NOTICE

All drawings located at the end of the document.

FINAL DRAFT

HISTORICAL INFORMATION SUMMARY AND PRELIMINARY HEALTH RISK ASSESSMENT OPERABLE UNIT NO. 3 SITES 200, 201 & 202

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

ENVIRONMENTAL RESTORATION PROGRAM

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FOREWORD

This document provides a summary of the existing site characteristics and environmental data related to contamination in three off-site reservoirs: Great Western Reservoir (Site 200), Standley Lake (Site 201), and Mower Reservoir (Site 202). The sediments in these reservoirs contain low levels of plutonium as a result of past activities at the Rocky Flats Plant. A qualitative evaluation of the human health risk associated with plutonium contamination in these three reservoirs is provided.

This report has been prepared to fulfill the requirements of the draft Interagency Agreement (IAG). The required actions for each reservoir under the IAG are: (1) "Submit all known and accumulated data describing, detailing or defining contamination within the reservoir(s) and tributaries of the reservoir(s) including surface and groundwater sources," and (2) "Submit a health risk assessment documenting the risks derived from all potential exposures with a no action alternative for remediation of the contamination."

The available data were collected over several years and have not been validated in accordance with current quality assurance protocols. However, it is believed that the validation of these data would show that they are not of sufficient specificity or quality to support a rigorous quantification of human health risks. Therefore, at this time, a qualitative evaluation is provided. The results presented in this report will be used as part of the scoping activities for the remedial investigation (RI) work plan to be prepared for sites 200-202. Data that will be acquired in the RI sampling and analysis phase will allow a rigorous quantitative human and ecological risk assessment to be performed.

EXECUTIVE SUMMARY

This document provides a summary of the existing site characteristics and environmental data related to contamination in three off-site reservoirs: Great Western Reservoir (Site 200), Standley Lake (Site 201), and Mower Reservoir (Site 202). The sediments in these reservoirs contain low levels of plutonium as a result of past activities at the Rocky Flats Plant. A qualitative evaluation of the human health risk associated with plutonium contamination in these three reservoirs is provided.

This document for sites 200, 201, and 202 of Operable Unit No. 3 (OU 3) was prepared in response to requirements in the draft Interagency Agreement (IAG) between the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH). The IAG identifies the following primary objectives for this report:

1. Submit all known and accumulated data describing, detailing or defining contamination within the reservoir(s) and tributaries of the reservoir(s) including surface and ground water sources, and

2. Submit a health risk assessment documenting the risks derived from all potential exposures associated with a no action alternative for remediation of the contamination.

After evaluating over 30 documents containing data relevant to sites 200-202, it became evident that it would be impractical to append the existing data to this document. The IAG data submission requirement is addressed by summarizing pertinent data in Section 2.0, by identifying specific data sources for each site in Table 2.1, and by including a bibliography listing general references and available documentation of data for sites 200-202 (Section 6.0). It also became apparent during the review of the data that the specificity and quality of existing information are insufficient to perform a rigorous quantitative human health risk assessment. In order to utilize data in a quantitative health risk assessment, the data must be validated, either by utilizing the EG&G Environmental Restoration Program data validation procedure or by collecting additional samples to verify that the data are representative. As a result, this document presents a Qualitative Human Health Risk

Assessment (Section 4.0) which evaluates release mechanisms, transport mechanisms, and exposure routes associated with sites 200-202.

While a quantitative risk assessment is needed to satisfactorily evaluate potential exposures to the public, the qualitative assessment presented in this report provides information which will enable future data collection activities (e.g. Remedial Investigations) to focus on the most significant exposure pathways. The following discussions provide a brief summary of the information provided in this report in support of the objectives listed above.

Sites 200 (Great Western Reservoir), 201 (Standley Lake), and 202 (Mower Reservoir) comprise three of the four sites within Rocky Flats Plant (RFP) OU 3. The three reservoirs are located outside the eastern boundary of the RFP. Great Western Reservoir serves as the municipal water supply for the City of Broomfield, while Standley Lake supplies water to the cities of Thornton, Northglenn and Westminster. Mower Reservoir is a much smaller, privately-owned impoundment used for agricultural purposes (i.e., cattle watering and irrigation).

Past environmental investigations of Great Western Reservoir and Standley Lake have shown that plutonium concentrations in the bottom sediments of both reservoirs exceed estimated background (nuclear testing fallout) concentrations. The elevated plutonium concentrations are attributed to historical airborne (fugitive dust) and waterborne releases from the RFP. These releases resulted primarily from routine RFP operations in the 1950s and 1960s. Pollution control measures implemented at the RFP since this time have effectively eliminated the source of the plutonium. In addition, surface water control measures now prevent runoff and effluent from the main RFP production facility from reaching the reservoirs. Studies to assess the impact of past RFP releases on these two reservoirs have concluded the following:

- Routine water quality monitoring indicates that water quality in the two reservoirs has not been measurably impacted by the plutonium in the sediments.

- Plutonium is the only contaminant of concern in the reservoirs attributable to RFP releases.

- A discrete plutonium-bearing layer of bottom sediments in both reservoirs has been covered by subsequent sedimentation. The highest plutonium concentrations are believed to occur in the deepest areas of each reservoir.

- Plutonium's high affinity for clay effectively immobilizes it in the sediments. No evidence of post-depositional migration through the sediment column has been detected.

Plutonium concentrations in Mower Reservoir have not been studied to date. Some of the land surrounding Mower Reservoir is known to have been contaminated by airborne particulates from the RFP. The reservoir is fed by a diversion from Woman Creek, which flows from the RFP and is also a possible historical source of plutonium in Standley Lake.

The results of the qualitative risk assessment (Section 4.0) indicate that airborne reentrainment of exposed sediments is the only credible environmental pathway that could impact the public. However, it is not possible to evaluate the potential risk to human health associated with this exposure pathway without performing a quantitative risk assessment.

The information presented in this report points to the following additional conclusions about sites 200-202:

- The concentrations of plutonium in the sediments in areas of highest exposure potential (i.e., near-shore areas) of Great Western Reservoir and Standley Lake are above background, but are below the CDH guideline for plutonium in soil of 0.9 picocurie per gram (pCi/g) (0.03 becquerel per gram (Bq/g)). The data supporting this conclusion, however, have not been validated.

- No data have been collected to assess plutonium concentrations in Mower Reservoir sediments. Because general site conditions and contaminant sources for Mower Reservoir appear similar to those for Great Western Reservoir and Standley Lake, it is expected that Mower Reservoir sediment plutonium concentrations are not significantly different than those in Great Western Reservoir and Standley Lake.

- Of the ten potential exposure pathways identified for the reservoirs, the airborne pathway from reentrainment of exposed sediments is the only credible pathway that will convey plutonium to human receptors from sites 200-202.

- Airborne plutonium concentrations measured by air monitors downwind of sites 200-202 have remained well below the 0.02 pCi/m^3 (0.0007 Bq/m^3) standard set by CDH.

- Residential tap water derived from Standley Lake and Great Western Reservoir is routinely analyzed for plutonium. Results consistently indicate that plutonium concentrations are well below CDH drinking water standards.

- Plutonium is strongly adsorbed to the clay-rich sediments typical in impoundments near the RFP. Studies have shown that plutonium in the reservoir sediment columns is effectively immobilized.

It is recommended that additional data necessary to support a quantitative risk assessment for sites 200-202 be collected. Additional data needs are identified in Section 4.11. The data will be collected during future Remedial Investigation activities. This report will serve as the basis for the Remedial Investigation scoping process.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANL	Argonne National Laboratory
ARARs	Applicable or Relevant and Appropriate Requirements
BEIR	Biological Effects of Ionizing Radiation
BNA	Base Neutral Acid
Bq	Becquerel
CDH	Colorado Department of Health
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWA	Colorado Hazardous Waste Act
Ci	Curie
cm	Centimeter (10^{-2} meters)
CSU	Colorado State University
DNA	Deoxyribonucleic acid
DOE	U.S. Department of Energy
dpm	Disintegrations per minute
EPA	U.S. Environmental Protection Agency
ft	Feet
g	Gram
gal	Gallon
GBq	Gigabecquerel (10^9 becquerels)
GI	Gastrointestinal
hr	Hour
IAG	Interagency Agreement
ICRP	International Commission on Radiation Protection
IHSS	Individual Hazardous Substance Site
in	Inch
K_d	Distribution coefficient
km	Kilometer (10^3 meters)
K_{ow}	Logarithmic octanol-water partition coefficient
l	Liter

LIST OF ACRONYMS AND ABBREVIATIONS
(continued)

lbs	Pounds
m	Meter
m^{-1}	Per meter
mCi	Millicurie (10^{-3} Curie)
mm	Millimeter (10^{-3} meter)
mph	Miles per hour
NCP	National Oil and Hazardous Substances Contingency Plan
NEPA	National Environmental Policy Act
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
OU	Operable Unit
pCi	Picocurie (10^{-12} Curies)
PuO_2	Plutonium dioxide
QA	Quality Assurance
QC	Quality Control
RAG	Risk Assessment Guide
RCRA	Resource Conservation and Recovery Act
RFP	Rocky Flats Plant
sec	Second
TGLD	Task Group on Lung Dynamics
USGS	United States Geological Survey, U.S. Department of the Interior
VOC	Volatile Organic Compound
yr	Year

LIST OF DEFINITIONS

Completed Exposure Pathway[1]: The route a chemical or radionuclide takes from a source to an exposed organism. A completed exposure pathway describes a discrete mechanism by which an individual or population is exposed to a chemical or radionuclide originating from the site. Each completed exposure pathway includes a source, a transport medium, a mode of uptake, and a receptor.

Data Quality Objectives[1]: Qualitative and quantitative statements to ensure that data of known and documented quality are obtained.

Data Validation: The quality assurance process of reviewing sample collection methods, sample handling and preservation, sample documentation and analytical procedures and results to evaluate the accuracy and reliability of data. Data are then classified as being quantitative, qualitative, or unusable.

Detection Limit[1]: The lowest value that can be reliably detected above the background noise of a given analytical instrument or method.

Health Risk Assessment: The assessment of chemical or radiological releases from a site and the analysis of public health threats resulting from those releases.

Qualitative Risk Assessment: An estimate of the likelihood of an adverse health effect by analyzing both exposure and dose response data in a non-numerical manner.

Quantitative Risk Assessment: Based on completed exposure pathways, probabilities that an individual will develop cancer over a lifetime of exposure are estimated from projected intakes and chemical/radionuclide-specific dose response information.

Risk: A unitless probability of an individual being affected by an event.

Risk Coefficient: For the purposes of this document, a unitless probability of an individual developing cancer from a chronic daily intake of plutonium averaged over seventy years.

[1] Definitions from the EPA Risk Assessment Guidance for Superfund (EPA 1986b).

1.0 INTRODUCTION

This document summarizes available historical information and presents a qualitative human health risk assessment for sites 200 (Great Western Reservoir), 201 (Standley Lake), and 202 (Mower Reservoir) of RFP OU 3 (Off-Site Releases). OU 3 is unique among Rocky Flats operable units in that it is located outside the RFP boundaries. These reservoirs have been the subject of numerous environmental studies and monitoring programs aimed at determining the extent to which each has been impacted by releases from the RFP. The RFP is owned by the DOE and contractor-operated by EG&G Rocky Flats, Inc., as a nuclear weapons research, development and production complex. The RFP is situated on 6,550 acres (2,653 hectares) of federal property 16 miles (26 kilometers) northwest of downtown Denver, Colorado (Figure 1-1).

In addition to the three reservoirs, OU 3 also includes site 199 (Contamination of the Land Surface). Site 199 is the subject of a Remedy Report which was submitted to EPA and CDH for review on October 26, 1990.

1.1 PURPOSE AND OBJECTIVES

The purpose and objectives of this report are derived primarily from the draft IAG between the CDH, the EPA, and the DOE (EPA, 1989a). The IAG identifies the following primary objectives for this report:

1. Submit all known and accumulated data describing, detailing or defining contamination within the reservoir(s) and tributaries of the reservoir(s) including surface and ground water sources, and

2. Submit a health risk assessment documenting the risks derived from all potential exposures associated with a no action alternative for remediation of the contamination.

After evaluating over 30 documents containing data relevant to sites 200-202, it became evident that it would be impractical to append the existing data to this document. The IAG data submission requirement is therefore addressed by summarizing pertinent data in Section 2.0, by identifying general references and specific data sources for each site in

Table 2.1, and by including a bibliography listing available documentation of data for sites 200-202 (Section 6.0).

The specific objectives for this report are listed below and are based upon these two primary objectives of the draft IAG:

- Describe reservoir site physical and chemical characteristics
- Provide a synopsis of environmental studies conducted to date at the reservoirs
- Formulate a conceptual model for contaminant fate and transport from the reservoirs
- Cite evidence to support or invalidate the conceptual model for each reservoir
- Provide a preliminary qualitative health risk assessment for the reservoirs, focusing on a no-action alternative
- Identify additional data needed to support a quantitative risk assessment for each reservoir.

1.2 REGULATORY BACKGROUND

The current iteration of the IAG (August 1990) groups Individual Hazardous Substance Sites (IHSSs, or sites) at the RFP into sixteen Operable Units (OUs), one of which is OU 3. OU 3 formerly was designated OU 10. The present RFP OU system has emerged from public comment and redevelopment of the IAG, which has increased the number of OUs from ten to sixteen and changed their relative order of priority.

The basis for the scope of work for investigation and remediation of RFP OUs is the IAG, which specifies an approach tailored to the particular requirements of the RFP. All response activities performed by the DOE under the IAG are to be consistent with applicable requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), the Resource Conservation and Recovery Act (RCRA), the Colorado Hazardous Waste Act (CHWA), and pertinent EPA guidance documents, and the National Environmental Policy Act (NEPA).

Great Western Reservoir is used as part of the municipal water supply for the city of Broomfield, while Standley Lake provides water for the cities of Westminster, Thornton and Northglenn. Federal and state water quality standards applicable to drinking water supply sources are monitored at these reservoirs through routine sampling and analysis. Local governments participate in public review of RFP plans and proposals as part of their involvement in decisions about RFP activities which may impact Great Western Reservoir or Standley Lake. Mower Reservoir is a much smaller, privately owned impoundment used for agricultural purposes (i.e., cattle and irrigation). Although not actively monitored, Mower Reservoir water quality is governed by CDH water quality classification and standards for the South Platte River basin (CDH, 1990b).

1.3 REPORT ORGANIZATION

The remainder of this report is organized into the following sections:

- Section 2.0 provides a discussion of site characteristics and history, and summarizes environmental studies conducted to date at sites 200, 201, and 202.
- Section 3.0 provides a description of the site conceptual model used in the qualitative human health risk assessment.
- Section 4.0 provides a qualitative human health risk assessment, including identification of data needed to conduct a quantitative human health risk assessment.
- Section 5.0 provides conclusions and recommendations.
- Section 6.0 provides a bibliography and references.

2.0 SITE BACKGROUND AND DESCRIPTION

The RFP fabricates metal components for nuclear weapons from plutonium, uranium, beryllium, and stainless steel. Support activities include chemical recovery and purification of recyclable transuranic radionuclides, and research and development in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry, and physics. These operations generate nonhazardous, hazardous, radioactive, and mixed radioactive waste streams (DOE, 1987). The 400 acre (162 hectare) main production facility of the RFP is surrounded by a 6,150 acre (2,491 hectare) buffer zone which delineates the RFP boundary (Figure 1-1).

The three OU 3 reservoirs are outside the eastern boundary of the RFP (Figure 2-1), 2 to 4 miles (3.2 to 6.4 kilometers) from the main production facility, and are downgradient and generally downwind of the plant. Each of these reservoirs has received some of its water from drainages flowing from the RFP during the operating history of the plant. Surface water control measures now prevent flow from the main production facility from reaching the reservoirs.

Environmental studies conducted to date of Great Western Reservoir, Standley Lake, and off-site reaches of Walnut and Woman Creeks have investigated the aquatic environment, sediments, and/or water quality in the reservoirs and drainages. Often several of these topics are addressed within the scope of a single study. Most of this work has focused on the presence and concentration of transuranic elements, primarily plutonium. Routine water quality monitoring is conducted by a number of agencies at Great Western Reservoir, Standley Lake, and streams discharging to the reservoirs. The RFP also monitors water quality in effluent discharged from the plant. The results consistently indicate that the water quality standards set forth for effluent from the RFP in the RFP National Pollution Discharge Elimination System (NPDES) permit are being achieved, and that nonradioactive contaminants from the RFP have not measurably impacted sediment and water quality at the reservoirs. Sections 3.0 and 4.0 are based upon the conclusion that radionuclides (specifically plutonium and its decay product, americium) are the only contaminants of concern in Great Western Reservoir and Standley Lake as a result of releases from the RFP. In the absence of site-specific data, the conclusion that radionuclides are the only contaminants of concern is applied to Mower Reservoir, since the mechanisms for any RFP-related contaminants to enter Mower Reservoir are likely to be similar to those for the other reservoirs.

The following sections summarize available information about site conditions, ownership and usage, past environmental investigations, and current water quality monitoring for each of the three reservoirs. Most of these data have not been validated and may not be of comparable quality owing to different methods of sample collection and analysis. Information cited in the following sections will be used to support the Conceptual Model of Contaminant Fate and Mobility in Section 3.0, the Qualitative Human Health Risk Assessment in Section 4.0, and the Conclusions and Recommendations in Section 5.0. It became apparent during review of the existing data that the specificity and quality of these data are insufficient to perform a rigorous quantitative risk assessment. In order to utilize data in a quantitative health risk assessment, the data must be validated as being "quantitative," either by using EG&G data validation procedures or by collecting additional samples to verify that the data are representative. Because the existing analytical data are of unknown quality and are not being used to support a quantitative human health risk assessment, these data are not specifically cited in this report. Table 2.1 lists available documents containing relevant analytical data for the three reservoirs, as well as documents summarizing the results of routine air quality and water quality monitoring at and near the RFP. This table is keyed to the Bibliography and List of References in Section 6.0. Studies listed in Table 2.1 and Section 6.0 contain analytical data to support their conclusions. While many of these conclusions are presented in this report, the reader should note that the underlying data may not meet current EPA, CDH, and DOE quality standards.

2.1 GREAT WESTERN RESERVOIR

2.1.1 Location and Description

Great Western Reservoir (IHSS 200) is located approximately 1.5 miles (2.4 kilometers) east of the RFP's eastern boundary in Sections 6 and 7 of Township 2 South, Range 69 West (T2S, R69W) (Figure 2-1). The reservoir is owned by the city of Broomfield and is utilized solely for the city's municipal water supply. Public access to Great Western Reservoir and the surrounding area is restricted (Broomfield, 1990).

Pre-construction information for the Great Western Reservoir site was not given in available references. The original reservoir was built in 1904 as an irrigation water supply. The dam has been enlarged on several occasions, most recently in 1958. The present maximum height of the dam is 69 feet (ft) (21 meters (m)) (Hydro-Triad, 1981). The present reservoir volume is 3,250 acre-feet (401 hectare-meters). The bottom and sides of the reservoir are unlined, meaning that the reservoir may be hydraulically connected to the ground water system in the area (Miller, 1990).

The U.S. Army Corps of Engineers utilized data from two existing boreholes near Great Western Reservoir as part of a 1989 evaluation for a surface water interceptor system for the reservoir. In these boreholes, alluvium surficial deposits are underlain by Arapahoe Formation bedrock at depths of 5 and 16 ft (1.5 and 4.9 m). Bedrock consists of interbedded sandstone, siltstone and claystone and dips slightly to the east (Corps of Engineers, 1989). The Arapahoe Formation averages 250 ft (76 m) in thickness in the area, and is underlain by several hundred feet (approximately 100 m) of shale comprising the upper portion of the Laramie Formation (USGS, 1976). It is expected that a similar stratigraphic sequence underlies Great Western Reservoir.

Great Western Reservoir is fed primarily by Clear Creek via Lower Church Ditch (USGS, 1980). Until recently, the reservoir also received influent from the north and south branches of Walnut Creek, both of which flow from the RFP. The two branches merge into a single drainage within the RFP boundary (Figure 2-1). A nonradioactive release at the RFP in 1989 prompted construction of a Walnut Creek diversion, known as the Broomfield

Diversion Ditch, just west of Great Western Reservoir. Walnut Creek flow from the RFP is now treated and diverted around Great Western Reservoir into the drainage below the reservoir outlet, where it combines with outflow from the reservoir. This effectively prevents runoff from the RFP main production facility from reaching Great Western Reservoir. Walnut Creek continues below Great Western Reservoir and eventually discharges into Big Dry Creek several miles downstream from the reservoir (USGS, 1980).

Within the RFP boundary, the North and South Walnut Creek drainages contain the A and B-series holding ponds, respectively. In North Walnut Creek, there are four ponds designated A-1, A-2, A-3 and A-4, from west to east (Figure 2-1). Ponds A-1 and A-2 are used only for spill control, and North Walnut Creek stream flow is diverted around them through an underground pipe. Pond A-3 receives North Walnut Creek stream flow and runoff from the northern portion of the RFP. Pond A-4 is utilized for surface water control and for overflow from Pond A-3 (Rockwell, 1988).

Five retention ponds located along South Walnut Creek are designated B-1, B-2, B-3, B-4 and B-5, from west to east (Figure 2-1). Ponds B-1 and B-2 are reserved for spill control. Pond B-3 receives treated effluent from the RFP sanitary sewage treatment plant. Ponds B-4 and B-5 receive surface runoff from the central part of the plant and routinely receive discharge from Pond B-3. Pond B-5 also collects overflow from Pond B-4 (Rockwell, 1988).

From the opening of the RFP in 1952 through approximately 1979, water containing decontaminated process and laundry effluent was discharged through the B-series ponds to South Walnut Creek (Rockwell, 1988). Cooling tower blowdown and treatment system steam condensate were discharged to the A-series ponds, which feed into North Walnut Creek. These discharges contained low levels of radionuclides which accumulated in the sediments of the holding ponds, Walnut Creek, and Great Western Reservoir (DOE, 1980).

The EPA concluded in 1975 that historic releases of contaminants from the RFP to Great Western Reservoir resulted primarily from the following activities (EPA, 1975):

- Early operational practices at the plant (1950s and 1960s)
- Reconstruction of the holding ponds between 1970 - 1973, which resuspended pond sediments and released some of this material to Great Western Reservoir
- A 1973 tritium release from the RFP (Section 2.1.2.2)
- Airborne transfer of radionuclides (primarily plutonium).

2.1.2 Environmental Investigations

The following is a chronological summary of environmental studies conducted to date of Great Western Reservoir and off-site reaches of Walnut Creek. Reports associated with these studies are incorporated by reference into the bibliography in Section 6.0.

2.1.2.1 Reservoir and Drainage Sediments

Extensive sampling of bottom sediments in Great Western Reservoir was conducted by the EPA in September 1970. The results indicated that a layer of sediment containing plutonium above the EPA estimated baseline level of $\leq$0.1 picocurie per gram (pCi/g) (0.0037 becquerel per gram (Bq/g)) is present in the bottom of the reservoir (EPA, 1973). EPA attributes the estimated baseline concentration of plutonium to worldwide fallout from nuclear weapons testing. The Walnut Creek inlet area and the central section of the reservoir (leading to the dam inlet) contained the greatest amount of plutonium. The lowest concentrations were found in the south arm, the shoreline area between the south arm and the dam, and the western portion of the north arm.

EPA resumed their investigation of plutonium in surface water sediments east of the RFP in September 1973. This phase of the study further documented plutonium concentrations in Great Western Reservoir. Sediment samples collected both by dredging and coring indicated that plutonium above expected baseline concentrations was present over almost the entire bottom of Great Western Reservoir. The study attributed the plutonium to releases from the RFP. The maximum plutonium concentration detected was approximately 40 times the $\leq$0.1 pCi/g (0.0037 Bq/g) estimated baseline concentration. The greater concentrations were found in the upper (younger) sections of the cores. The results confirmed the areal distribution of plutonium delineated by the 1970 study, except that the highest concentrations were found in the deepest areas of the reservoir rather than in the Walnut Creek inlet area. It was also observed that plutonium-239 concentrations in the uppermost sediment layer increased significantly in the three years between the two studies. This increase was traced to an influx of sediment resuspended from the RFP holding ponds during pond reconstruction activities (EPA, 1975).

The 1973 EPA study also sought to confirm the estimated plutonium baseline (background) level by sampling sediments from Front Range reservoirs believed to be unaffected by the RFP. Two dredge samples were collected from Cherry Creek Reservoir, two from Marston Lake, and five from Ralston Reservoir. With one exception, analysis of these nine samples yielded plutonium-239 levels well below 0.1 pCi/g (0.0037 Bq/g), substantiating EPA's estimated baseline concentration of $\leq$0.1 pCi/g (0.0037 Bq/g) (EPA, 1975).

In 1974, Battelle Northwest Laboratories conducted an investigation of radionuclide concentrations in reservoir and stream sediments near the RFP. The results indicated that levels of plutonium-239, plutonium-240 and americium-241 in the sediments of Great Western Reservoir and streams flowing into the reservoir exceeded "baseline levels" (presumably the EPA baseline of $\leq$0.1 pCi/g (0.0037 Bq/g). Total inventories of plutonium and americium in reservoir sediments were estimated at 244 millicurie (mCi) and 73 mCi (9.02 and 2.7 GBq), respectively. Cesium-137 levels were at or below expected baseline concentrations. Age-dated sediment cores collected during this study from Great Western Reservoir demonstrated two separate periods of plutonium deposition, 1968-1969 and 1959-1964. Both periods coincide with recorded, controlled waterborne releases from the RFP. Worldwide fallout from atmospheric nuclear weapons testing may also have contributed to the plutonium in the 1968-1969 sediment layer. An additional finding was that decay of naturally-occurring radium-226 in surface and domestic waters near the RFP represents a much greater relative contribution to public radiation exposure than does plutonium released from the RFP (Battelle, 1974).

Also in 1974, Colorado State University (CSU) conducted a study of plutonium in aquatic systems of the RFP environs. This study concluded that the clay fraction of RFP sediments has an extremely high affinity for plutonium and, left undisturbed, provides an excellent retention mechanism for plutonium in the aquatic system. Laboratory studies related to this investigation showed that the adsorption of plutonium by the sediments was rapid and essentially irreversible (CSU, 1974).

The RFP aquatic environment was also studied in 1975 by Dow Chemical Company. According to this study, plutonium in surface water impoundments is not readily transported from the impoundments. Consequently, the majority of the plutonium released through RFP surface waters has been contained in the on-site holding ponds. The Dow study also confirmed that concentrations of plutonium above EPA's estimated baseline levels were present in Walnut Creek sediments and in the sediments of Great Western Reservoir. Plutonium concentrations in the creek sediments increased downstream, suggesting downstream migration of plutonium released at an earlier time. The highest plutonium concentrations in the reservoir sediments were found near the Walnut Creek inlet and along the dam, where the highest sedimentation rates occur. The Dow study concluded that releases of plutonium from the RFP waste treatment plants coincided with periods of high suspended solids in the influent from the creek and holding ponds (Thompson, 1975).

Rockwell International conducted a two-phase investigation of transuranic elements in the sediment on the Great Western Reservoir overflow spillway in 1979 - 1980. It was determined that sediments ranging in depth from three to nine feet had accumulated on the spillway in the fourteen years prior to the studies. Levels of plutonium-239, plutonium-240 and americium-241 in spillway sediment samples were near regional baseline concentrations. Plutonium concentrations did not exceed the 0.9 pCi/g (0.03 Bq/g) activity screening level adopted by the CDH for soil. Plutonium and americium concentrations varied little with depth. This finding supported the conclusion that spillway sediments were deposited through a combination of hillslope erosion, wave action and sediment mixing, rather than the continuous lacustrine deposition typical of the reservoir bottom deposits (Rockwell, 1979; Rockwell, 1980).

Sediment samples were collected from over 60 locations within Great Western Reservoir during a 1983 Rockwell International study. Sedimentation rates based on core samples were determined to vary from approximately 0.5 - 0.75 inches per year (in/yr) (1.3 - 1.9 centimeters per year (cm/yr)), with the higher rates in the eastern, deeper portion of the reservoir. The study confirmed that plutonium occurred in a distinct sediment layer corresponding with historical releases from the RFP. It was concluded that sediments contaminated with plutonium in Great Western Reservoir had been covered by subsequent sedimentation, and that no evidence existed of post-depositional migration of plutonium through the sediment column (Rockwell, 1988).

2.1.2.2 Reservoir and Drainage Water Quality

Surface water quality in North and South Walnut Creeks and in Great Western Reservoir has been monitored since 1951 (Rockwell, 1988). Analytical results for transuranic elements, ions, metals and organic compounds are maintained by CDH, the City of Broomfield, and the RFP, and are available through the CDH Rocky Flats Program Unit. Studies of surface water quality conducted since 1951 have reported transuranic element concentrations well below EPA drinking water standards.

A 1973 EPA study concluded that plutonium and uranium levels in water samples from Great Western Reservoir and Walnut Creek were essentially at baseline concentrations of <0.03 picocuries per liter (pCi/l) (<0.001 Bq/l) (EPA, 1973).

An accidental release of tritium in 1973 from the RFP into Walnut Creek and Great Western Reservoir was the focus of another EPA study. EPA estimated that the release resulted in a total committed dose of 4 millirem (0.04 millisievert) to the average individual using the reservoir as a source of drinking water. EPA found that this dose had minimal impact on public health and did not recommend any mitigative actions (EPA, 1974).

In 1974, Battelle conducted an investigation of radionuclide concentrations in reservoirs, streams and domestic tap waters near the RFP. Plutonium-239, plutonium-240, and americium-241 levels in Broomfield tap water were substantially below EPA National Primary Drinking Water standards of 3,700 dpm/l (62 Bq/l) for plutonium and 33 dpm/l (0.55 Bq/l) for total long-lived alpha activity (Battelle, 1974).

Dow Chemical concluded in 1975 that, within the limits of sampling and analytical variation, reservoir and domestic water radiological contaminants near the RFP were essentially at background levels (Thompson, 1975).

The DOE published a final environmental impact statement for the RFP in 1980. Water samples were collected from several water bodies in the vicinity of the RFP, including Walnut Creek and Great Western Reservoir, for analysis of radionuclides. Tap water also was sampled in nine nearby communities. Plutonium and tritium concentrations in these samples were lower than the EPA standards for drinking water (DOE, 1980).

A 1981 Rockwell International report compared gross alpha and plutonium levels in Great Western Reservoir water and Broomfield drinking water with levels in other local water bodies and drinking water supplies. All comparisons (with the exception of plutonium in Ralston Reservoir) showed levels of these analytes in regional water to be greater than or similar to those in Great Western Reservoir and Broomfield drinking water. This report stated that, within the limits of analytical uncertainty, no transuranics were present in RFP area waters prior to construction of the plant in 1951 (Rockwell, 1981).

The most recent available set of compiled and summarized surface water quality data is presented in the 1988 RFP annual environmental monitoring report (Rockwell, 1989). During 1988, maximum concentrations of plutonium, americium, uranium, and tritium in area drinking waters, and in samples from the Walnut Creek sampling station on the RFP east boundary, were below EPA and State of Colorado drinking water standards.

The City of Broomfield samples Walnut Creek immediately east of the RFP on a monthly basis and tests for eight VOCs. An automatic sampler at the same location collects a composite water sample each week for gross alpha and gross beta analysis. Weekly samples also are collected by Broomfield from Walnut Creek below Great Western Reservoir and analyzed for gross alpha and gross beta. Water entering the Broomfield water treatment plant from the reservoir is monitored monthly for eight VOCs. Treated Broomfield tap water is also monitored weekly for gross alpha and gross beta, and monthly for eight VOCs (CDH, 1989).

The CDH monitors ground water in wells within the RFP along the eastern plant boundary on a quarterly basis. Samples from these wells are analyzed for selected metals, VOCs, inorganic compounds, and radionuclides. CDH sampled a number of private wells east of the RFP approximately three years ago, but does not routinely monitor ground water quality outside the RFP boundary. CDH also conducts quarterly sampling of Great Western Reservoir for selected herbicides, pesticides, metals, base neutral acids (BNAs), and radionuclides. Broomfield water treatment plant influent from Great Western Reservoir is analyzed weekly by CDH for selected radionuclides (CDH, 1990b).

2.2 STANDLEY LAKE

2.2.1 Location and Description

Standley Lake (IHSS 201) is a large reservoir located approximately 2 miles (3.2 kilometers) southeast of the RFP's eastern boundary (Figure 2-1) in Sections 16, 17, 20, 21, 22, and 28, T2S R69W. Uses of the reservoir include water supply and recreation. The reservoir has been owned by The Farmers Reservoir and Irrigation Company of Brighton, Colorado since its construction between 1909 - 1919. Although the dam has undergone periodic maintenance and reconstruction, most recently in 1978, Standley Lake's present volume of 43,000 acre-feet (5,300 hectare-meters) has remained relatively unchanged since its construction. Approximately 67 percent of the reservoir water is used as municipal water supply for the cities of Westminster, Northglenn and Thornton. The remaining 33 percent is transported through irrigation ditches to agricultural areas northeast of the lake, primarily between Broomfield and Fort Lupton. Standley Lake receives approximately 95 percent of its water from Clear Creek via an irrigation ditch, but is also fed by Woman Creek flowing from the southern side of the RFP (Farmers, 1990).

A geologic characterization of Standley Lake was performed by Mineral Systems, Inc. in 1982 to provide data for the enlargement of the dam and reservoir. Bedrock outcrops at various locations around the lake consist of claystone with interbedded sandstone lenses, probably of the Arapahoe Formation. These units dip gently to the northeast. Overlying the bedrock are surficial deposits consisting of a series of alluvial terraces, colluvium, and minor other deposits (Hydro-Triad, 1982). No faults have been identified in the area. The Arapahoe Formation averages 250 ft (76 m) in thickness in the area, and is underlain by several hundred feet (approximately 100 m) of shale comprising the upper portion of the Laramie Formation (USGS, 1976). It is expected that a similar stratigraphic sequence underlies Standley Lake.

Within the RFP boundary, the Woman Creek drainage contains the two C-series holding ponds, Ponds C-1 and C-2 (south and east of the main production area, respectively) (Figure 2-1). Pond C-1 receives flow from Woman Creek. This flow is diverted around Pond C-2 and into the Woman Creek channel downstream. Pond C-2 receives surface runoff from the South Interceptor Ditch along the southern side of the RFP main production area (Rockwell, 1988). Pond C-2 water formerly was discharged into the Woman Creek drainage in accordance with the National Pollution Discharge Elimination System (NPDES) permit for the RFP. Under a recent agreement between the RFP and the City of Broomfield, water is now pumped from Pond C-2 into a treatment facility, then through an aboveground pipeline to the Broomfield Diversion Ditch, where it is discharged in accordance with an amended NPDES permit. The discharge agreement with Broomfield is effective through 1990 (Mende, 1990). These surface water controls effectively prevent runoff from the RFP main production facility from reaching Standley Lake.

Radioactive materials released from the RFP may have been transported to Standley Lake through surface water (primarily in suspended sediments) and/or airborne particulates (fugitive dust). Between 1952 and 1973, the RFP discharged water treatment facility filter backwash into Pond C-1, which discharges into Woman Creek. At present, only collected runoff and natural ground water seepage flow into the Woman Creek drainage (Rockwell, 1989).

2.2.2 Environmental Investigations

The following is a chronological summary of environmental studies conducted to date of Standley Lake and off-site reaches of Woman Creek. Many of the studies conducted at Great Western Reservoir (Section 2.1.2) also included Standley Lake. Reports associated with these studies are incorporated by reference into the bibliography in Section 6.0.

2.2.2.1 Reservoir and Drainage Sediments

The EPA sampled bottom sediments from Standley Lake in 1970. The results indicated possible areas of plutonium contamination above the estimated $\leq$0.1 pCi/g (0.0037 Bq/g) baseline concentration in the deeper areas of Standley Lake. EPA attributes the estimated baseline concentration of plutonium to worldwide fallout from nuclear weapons testing, and concluded that elevated plutonium in Standley Lake resulted from unspecified releases from the RFP (EPA, 1973).

EPA resumed their investigation of plutonium in surface water sediments east of the RFP in 1973. Analysis of Standley Lake sediment samples yielded two plutonium detections above estimated baseline concentrations, but failed to confirm the 1970 finding of possible contaminated areas within the reservoir (EPA, 1975).

During a 1974 investigation of radionuclides in the sediments of reservoirs and streams near the RFP, Battelle Northwest Laboratories collected a single sediment core from Standley Lake. This sample contained plutonium-239, plutonium-240, and americium-241 above EPA estimated baseline levels. Based upon this single core sample, Battelle extrapolated total plutonium and americium inventories for Standley Lake sediments at 60 mCi and 18 mCi (2.2 and 0.7 GBq/g), respectively. The sample also suggested that cesium-137 levels in Standley Lake sediments were typical of atmospheric fallout baseline levels. An additional finding was that decay of naturally-occurring radium-226 in surface and domestic waters near the RFP represents a much greater relative contribution to public radiation exposure than does plutonium released from the RFP (Batelle, 1974).

Studies of plutonium in the aquatic systems of the RFP environs in 1974 and 1975 concluded that: (1) plutonium rapidly and almost irreversibly attaches itself to clay sediments (CSU, 1974), and (2) plutonium in surface water impoundments does not move very far or very rapidly through subsurface waters, meaning that the majority of the plutonium released through RFP surface waters has been contained in the on-site holding ponds (Thompson, 1975).

The DOE in 1978 correlated a sediment core from Standley Lake to a 14-year period of time, which was then used to determine when plutonium entered the reservoir. It was concluded that plutonium concentrations in the sediments have exceeded baseline levels since 1966, peaked in 1969, and have declined after 1969. The report attributed 70 percent of the plutonium in Standley Lake to releases from the RFP and speculated that this plutonium was transported both by soil erosion within the lake drainage basin (i.e. surface water) and by airborne particulates (DOE, 1978).

Rockwell International conducted a study of Standley Lake sediments in 1984 to evaluate plutonium concentrations and to compare the results with previous work. The findings corroborated those obtained by the EPA and Battelle, and indicated that plutonium had remained below EPA estimated baseline levels of $\leq$0.1 pCi/g (0.0037 Bq/g) since these earlier studies were conducted. The report also concluded that plutonium contamination in Standley Lake sediments had been buried by subsequent sedimentation, and that post-depositional migration of plutonium through the sediment column was not evident (Rockwell, 1984).

In 1989, the CDH analyzed various species of fish collected from Standley Lake to determine if they were safe for human consumption. The fish were analyzed for selected metals, radionuclides (including plutonium-239, plutonium-240, and cesium-137), and priority organic pollutants. No radionuclides were detected in the fish; however, low concentrations of cadmium, mercury, selenium, and the pesticides DDT, DDE, DDD, and malathion were detected in some or all species. The report stated that the source(s) of these contaminants was indeterminate, but that none of them were unique to the RFP. It was concluded that the contaminants may have originated from a variety of sources in the watershed, including water diverted from Clear Creek, which contributes 96 percent of the influent to the lake (CDH, 1990c).

2.2.2.2 Reservoir and Drainage Water Quality

The quality of surface water in Woman Creek and Standley Lake has been monitored on a regular basis by the RFP and the CDH. Studies of Standley Lake water quality to date have indicated that transuranic element levels are below EPA standards for drinking water. Transuranic element concentrations are below detection limits in Westminster drinking water. Numerous publications list the results of analyses for transuranic elements, ions, metals, and organic compounds, but little of this information has been comprehensively reviewed, evaluated, and summarized. The most recent available set of compiled and summarized surface water quality data is presented in the 1988 RFP annual environmental monitoring report (Rockwell, 1989). The most current data are available through the CDH Rocky Flats Program Unit and the City of Westminster Radiation Data Monthly Monitor Report.

A 1973 study by the EPA concluded that plutonium and uranium levels in water samples from Standley Lake were essentially at baseline concentrations of <0.03 pCi/l (0.001 Bq/l) (EPA, 1973).

Battelle Northwest Laboratories analyzed Standley Lake water as part of their investigation of radionuclide concentrations in reservoirs, streams and domestic waters near the RFP. Plutonium-239, plutonium-240, and americium-241 concentrations were above detection limits but below the EPA National Primary Drinking Water standards in Standley Lake water. These radionuclides were below detection limits in Westminster drinking water (Battelle, 1974).

The final environmental impact statement for the RFP published sample analytical results from several water bodies in the vicinity of the RFP, including Standley Lake, and from tap water sampled in nine nearby communities. Plutonium and tritium concentrations in these samples were less than the EPA standards for drinking water (DOE, 1980).

The Cities of Northglenn, Thornton and Westminster each monitor raw water influent from Standley Lake at their respective water treatment plants for VOCs, gross alpha and gross beta. Westminster also monitors treated (tap) water for gross alpha and gross beta. Woman Creek is sampled immediately east of the RFP boundary once each month by the City of Thornton and analyzed for 59 VOCs. Another location along Woman Creek is sampled weekly for gross alpha and gross beta analysis. Standley Lake water is sampled monthly near the Westminster treatment plant inlet and analyzed for 59 VOCs. Water is also sampled monthly near the Standley Lake dam at six different depths and analyzed for gross alpha and gross beta (CDH, 1989).

The CDH monitors ground water in wells within the RFP along the eastern plant boundary on a quarterly basis. Samples from these wells are analyzed for selected metals, VOCs, inorganic compounds, and radionuclides. CDH sampled a number of private wells east of the RFP approximately three years ago, but does not routinely monitor ground water quality outside the RFP boundary. CDH also conducts quarterly sampling of Standley Lake for analysis of selected herbicides, pesticides, metals, BNAs, and radionuclides. Westminster water treatment plant influent from Standley Lake is analyzed weekly by CDH for selected radionuclides (CDH, 1990b).

2.3 MOWER RESERVOIR

Very little documentation exists for Mower Reservoir (IHSS 202), a small, privately-owned impoundment located just southeast of the RFP in Section 18, T2S R69W (Figure 2-1). The reservoir is fed by Woman Creek via an irrigation ditch that originates within the RFP boundary (USGS, 1980). Mower Reservoir is used for agricultural purposes, primarily cattle watering and irrigation, and fluctuates in capacity depending upon water supply and demand. It covers an area of approximately 9 acres (3.6 hectares) and is roughly 50 ft (15 m) deep at its deepest point. Mower Reservoir is located on land which was the subject of a lawsuit against the RFP by several landowners, alleging contamination of the land surface by releases from the plant. Part of this land has been designated IHSS 199 and is the focus of a Remedy Report which was submitted to EPA and CDH for review on October 26, 1990.

The geological setting at Mower Reservoir is inferred to be similar to that described for Great Western Reservoir (Section 2.1.1) and Standley Lake (Section 2.2.1). Surficial deposits ranging from 10 to 30 ft (3 to 9 m) thick consist of alluvium along ridge crests and colluvium on drainage slopes. The underlying Arapahoe Formation is composed of claystone with interbedded sandstone lenses. The Arapahoe Formation averages 250 ft (76 m) in thickness in the area, and is underlain by several hundred feet (approximately 100 m) of shale comprising the upper portion of the Laramie Formation (USGS, 1976).

Studies conducted to date of reservoirs near the RFP have not specifically addressed Mower Reservoir. Environmental investigations of the surrounding land (IHSS 199) have concluded that the primary source of contamination (chiefly plutonium) at IHSS 199 was airborne particulates from the RFP. It is expected that Mower Reservoir received similar amounts of plutonium through airborne transport as the nearby land surface. Plutonium concentrations measured in 1987 in surface soils around Mower Reservoir (Rockwell, 1987) averaged several times lower than those measured in Great Western Reservoir sediments, and several times higher than those measured in Standley Lake sediments. Because it is fed by Woman Creek, Mower Reservoir may also have been affected by surface water contaminants believed to have contributed to plutonium levels in Standley Lake sediments (Section 2.2.2). Surface water in the Woman Creek drainage is controlled by the C-series holding ponds (Figure 2-1). It has been speculated that concentrations of radionuclides in Mower Reservoir sediments should not exceed levels measured in Great Western Reservoir and Standley Lake (DOE, 1986).

2.4 OTHER RELEVANT STUDIES

Several proposed or ongoing investigations within the boundaries of the RFP may produce data which is relevant to the OU 3 reservoirs. Although investigations at on-site OUs have progressed to varying stages of completion, most are in the initial assessment stage.

Investigations of Woman Creek (OU 5) and Walnut Creek (OU 6) will help to determine whether these drainages were pathways for off-site contamination which might eventually have reached Standley Lake and Great Western Reservoir. Studies of surface soil contamination in the eastern part of the RFP as part of the ongoing investigation of RFP OU 2 may elucidate the role of wind in transporting contaminants to the OU 3 reservoirs, particularly Mower Reservoir.

In 1988, the Colorado School of Mines (CSM) presented a proposal to the RFP to study radionuclides in the sediments of Colorado Front Range lakes which had not been affected by releases from the plant (CSM, 1988). As a result of this proposal, a study was conducted for the RFP by CSM of Halligen Reservoir and Wellington Lake, located north of Fort Collins, CO and southeast of Bailey, CO, respectively. The objectives were to more firmly establish baseline radionuclide concentrations due to atmospheric fallout so that "excessive" values could be operationally defined, to compare sedimentation rates for the "background" reservoirs with those for reservoirs near the RFP, and to determine whether radionuclides were subject to any post-depositional bioturbation. The study determined that plutonium concentrations in the sediments of the two reservoirs peaked at 0.19 $\pm$0.02 pCi/g (0.007 $\pm$0.00074 Bq/g), and proposed this value as a baseline concentration for plutonium in Colorado Front Range reservoirs (CSM, 1990). This level is somewhat higher than EPA's estimated plutonium baseline concentration of $\leq$0.1 pCi/g (0.0037 Bq/g). It should be noted that the CSM study was presented to the RFP in May 1990, and has not yet been formally reviewed by the RFP or published for the scientific community outside the RFP.

3.0 CONCEPTUAL MODEL OF CONTAMINANT FATE AND MOBILITY

Utilizing the information obtained in past studies (Section 2.0), a conceptual model of contaminant transport and exposure pathways for sites 200-202 is presented here for use in the evaluation of the potential risks of reservoir contamination to human health (Figure 3-1). For an exposure pathway in the conceptual model to be considered complete it must contain the following components:

- Contaminant Source: The primary current source area is the plutonium-contaminated reservoir sediments of sites 200-202. Plutonium from sites 200-202 could be released to air, ground water, surface water, or biota. Each of these media can subsequently become a secondary source for further releases.

- Contaminant Release Mechanism: Potential release mechanisms for plutonium from the reservoir sediments include resuspension into air, surface water runoff, infiltration/percolation into ground water, and biotic uptake. The conceptual mode identifies both primary release mechanisms (those mechanisms which release contaminants directly from the source area) and secondary release mechanisms (those mechanisms which release contaminants from secondary media contaminated by the source area).

- Transport Media: Once plutonium is released it can be transported within transport media to exposure points. The transport media can be air, ground water, surface water, or biota. Behavior and fate of plutonium in these media is important relative to exposure routes and receptors. The conceptual model identifies both primary transport media (the media in which contaminants exist at the source area) and secondary transport media (those media in which contaminants are transported away from the source area).

- Exposure Route: Any point of potential contact with a contaminated medium is an exposure point. Exposure routes are determined according to the media contaminated and the anticipated activities at the exposure points. Exposure route can be by ingestion, inhalation, or dermal contact.

- Receptor: The receptors are individuals potentially exposed to contaminants at the exposure points.

The conceptual model provides an overview of all the potential exposure pathways that may result from releases from and/or into each transport media. Some of these pathways have a greater exposure potential than others. Significant pathways which are common to each reservoir are identified in Section 4.0 by evaluating the fate and mobility of the contaminant in each potential media that is included in the conceptual model. Reservoir specific pathway issues are then discussed in Section 4.8.

The various elements of the conceptual model are explained in the following sections.

3.1 HISTORIC SOURCES

As described in Section 2.0, contamination attributable to releases from the RFP has been documented at Standley Lake and Great Western Reservoir. Environmental investigations conducted to date have determined that the only contaminant from the RFP above background levels in these reservoirs is plutonium (DOE, 1980). These investigations have further concluded that the plutonium was introduced to the reservoirs as a result of historical RFP releases, and that subsequent controls placed on release pathways within the RFP have effectively prevented further releases to the reservoirs. Ground water quality monitoring along the eastern boundary of the RFP indicates that ground water has not been a pathway for contaminant migration to the reservoirs.

3.2 SOURCE AREA CHARACTERIZATION

Plutonium fate and mobility in the waters and sediments which constitute the primary transport media at sites 200-202 depend on the physical and chemical properties of the media and the plutonium.

At the Eh and pH of typical environmental conditions, plutonium (predominantly plutonium dioxide) is virtually insoluble in water. The solubility product of plutonium ranges from 10^{-23} to 10^{-54} (Allard et al., 1983), indicating that plutonium will not exist as a true ionic species in water. Plutonium solubility and subsequent mobility may increase in the presence of dissolved organic matter, carbonate, fluoride, nitrates, chlorides, or other complexing agents in the water. Typically, however, plutonium attaches to particulate matter (suspended solids) by electrostatic attraction and remains tightly bound to these particulates in water. Therefore, the great majority of any plutonium occurring in reservoir waters will be adsorbed onto suspended solids in the water. Sediment load is the main water transport mechanism for plutonium under virtually all environmental conditions.

In stagnant impoundments such as holding ponds and reservoirs, suspended solids gradually settle out of water to form bottom sediments. It has been shown that clay-rich sediments, such as those in sites 200-202, have an extremely high affinity for plutonium, effectively immobilizing it in the sediment (CSU, 1974). While it is possible that elevated concentrations of complexing agents combined with a relatively high percolation rate through the sediments might mobilize the plutonium, no evidence of plutonium migration in the sediments has been detected (DOE, 1980).

Density stratification of lake waters in summer results in a reducing environment in deeper water. Under reducing conditions, the distribution coefficient of plutonium, which is the ratio of concentrations in soil (or sediment) to concentrations in water, may be three to tenfold lower than under typical reservoir conditions, meaning that plutonium mobility may increase slightly. The magnitude of this increase is not significant, however, in terms of overall plutonium mobility (ANL, 1986).

Based upon the conceptualization of plutonium chemistry in the environment presented above, nearly all of the plutonium in sites 200-202 is expected to be adsorbed to clay in bottom sediments. Studies cited in Sections 2.1.2 and 2.2.2 have indicated that the plutonium in Great Western Reservoir and Standley Lake occurs in a discrete sediment layer in each reservoir which has been buried by subsequent sedimentation. The highest plutonium concentrations appear to exist in the deepest areas of the reservoirs.

3.3 RELEASE MECHANISMS AND EXPOSURE PATHWAYS

As shown in Figure 3-1, potential release mechanisms and transport media can combine in a variety of ways to transport contamination from the reservoirs to human and other biotic receptors. These release mechanisms and exposure pathways are potential, and their identification here is not meant to imply that they will occur or be significant at the reservoirs. The contaminant source characterized in the preceding section is a semi-consolidated mass buried in the sediment of each reservoir, and is not readily available for release into the environment by any of the mechanisms described below. Probabilities of occurrence are discussed in Section 4.0.

Direct contact with contaminated reservoir sediments or consumption of water containing contaminated solids are two obvious pathways. Direct contaminant uptake by aquatic plants and animals might also occur. Once biotic receptors have been affected, the contaminants can move up the food chain to human receptors. Biotic uptake of plutonium is addressed in Section 4.5.2.2.

Movement of contaminants by wind is possible where affected sediments are exposed to air, or if wind speed is sufficiently strong to strip water droplets containing suspended solids from the surface of the reservoirs. Affected sediments in drainages are unlikely to contain a significant fraction of fine materials which might be mobilized by wind. A more conceivable scenario is wind transport of exposed reservoir sediments when the water level falls during dry periods and/or periods of high water demand. The amount of contaminant released would depend in part upon the depth, areal extent, and concentration of plutonium in the sediments. Plutonium released into the air could be inhaled directly by receptors or could affect downwind soil and/or plant surfaces as settled dust. Plants growing in affected soils might then incorporate contaminants into their biomass. Humans, livestock or other animals could in turn be affected by consuming these plants.

Resuspension of contaminated sediments by wave action, bottom-dwelling organisms, lake turnover (i.e. density convection currents), or high runoff might increase contaminant concentrations in reservoir water. Water discharged from the reservoirs into surface drainages may be used for drinking water or irrigation, be utilized or ingested by nearby plants and animals, or recharge the ground water system. Irrigation water, obtained directly from the reservoir or from downstream, could affect the crops, soils and ground water where it is applied.

Intermittent or continuous infiltration into the ground water system may occur from surface water impoundments or drainages. Depending upon the physical and chemical nature of the sediments and water, infiltration through contaminated sediments can leach plutonium down to the water table. Although this scenario is conceivable, its likelihood of occurrence at sites 200-202 is remote because of plutonium's virtual insolubility in water and strong adsorption to clay sediments. If, however, the plutonium does enter the ground water system, it may be transported away from the source area through ground water flow. Because of its high typical distribution coefficient, plutonium would not be expected to migrate very readily in ground water (ANL, 1986). In some environments, however, plutonium has been shown to bind to colloidal particles which are unaffected by the forces that normally act to retard plutonium movement through ground water systems, and to migrate significant distances through ground water flow (Penrose, et al., 1990). Contaminant pathways from affected ground water are similar to those outlined above for surface water. Ground water may be utilized for public water supply or irrigation (i.e. water wells), may be transpired by plants, or may eventually recharge into surface water.

Filtration of influent water at water treatment plants effectively separates most suspended solids from the water. Any plutonium sorbed onto these particles will therefore also be removed. The nature and fate of sediments removed from reservoir water in treatment plants must therefore be considered in order to completely address plutonium fate and mobility in the reservoirs.

Water from Great Western Reservoir is filtered at the Broomfield water treatment plant. The filters are routinely backwashed into a settling lagoon at the plant. Accumulated backwash sludge is periodically removed from the lagoon and analyzed for a variety of parameters, including plutonium, prior to disposal. Plutonium has not been detected in the sludge above background levels in past analyses. Sludge was last analyzed and removed from the lagoon approximately five years ago (Broomfield, 1990). Filtration of Standley Lake influent occurs at the Northglenn, Thornton and Westminster water treatment plants. Discussions with personnel at each of these facilities indicate that filter backwash sludge has not been analyzed for plutonium or gross alpha activity.

4.0 QUALITATIVE HUMAN HEALTH RISK ASSESSMENT

A qualitative human health risk assessment for sites 200-202 is presented in this section. The objectives of this assessment are to identify exposure pathways which may pose a significant threat to human health, and to identify additional information needed to perform a quantitative assessment. The qualitative assessment identifies the plausible exposure pathways and qualitative risks which are common to each reservoir based on the no action alternative (baseline risk assessment). Additional factors which are specific to each reservoir are then discussed.

At the time of this report, the specificity and quality of existing data for sites 200-202 are insufficient to perform a rigorous quantitative human health risk for the site. Due to the inherent uncertainty of qualitative risk assessment, it will not be possible in this assessment to compare the relative risks of the no action scenario for the three sites; however, the media-specific pathways, routes of uptake, and potential human receptors are the same for all three sites. Because the plutonium deposited in the sediment has not been adequately characterized for sites 200-202, it is not possible to calculate a risk coefficient for any of the three sites. A quantitative risk assessment cannot therefore be developed that complies with the EPA Risk Assessment Guidance (EPA, 1989b).

All of the data reviewed (see Section 6.0 for a list of references) indicate that plutonium is the only contaminant of concern at sites 200-202 that can be attributed to RFP historical releases. Media-specific analyses of other radionuclides present at the RFP, such as americium-241, have not been performed for these sites. If these radionuclides do occur at sites 200-202, they would likely exist in small quantities compared to plutonium. This statement is based on the ratios of Pu/Am in the weapons grade materials handled at RFP. The initial historic ratio of Pu/Am was 15:1. As a result of the radioactive decay of plutonium-241 and subsequent ingrowth of americium-241, it is likely that the current ratio is closer to 5:1 (DOE, 1988). Because americium produces almost twice the internal dose as plutonium (ICRP, 1979), determination of its magnitude and extent must be accomplished for a quantitative risk assessment. Since available data for americium concentration in the reservoirs are incomplete and not definitive, its contribution to this qualitative assessment cannot be addressed. However, since the plutonium/americium ratio is 1:0.2 and the internal hazard ratio is approximately 1:2, a simplifying assumption is made that americium provides 40 percent of the hazard of the plutonium at sites 200-202. The Pu/Am ratio does indicate that the presence of americium would not increase the magnitude of the risk at sites 200-202. Therefore, only plutonium will be addressed in this risk assessment.

4.1 CONCEPTUAL APPROACH

Sites 200-202 are reservoirs that contain sediments contaminated with low (up to 7 pCi/g) levels of plutonium that exceed the CDH plutonium in soil standard of 0.9 pCi/g in some locations. The source of this plutonium is historic releases of airborne and waterborne plutonium from the RFP. The historic sources of plutonium contamination to sites 200-202 have been effectively eliminated by controls on discharge and surface water flow. Therefore, this assessment is based on the assumption that the plutonium present at sites 200-202 represents the highest possible concentration that will be available for human receptor impact.

This is a qualitative risk assessment that uses hazard rankings (Section 4.5.3) instead of plutonium concentration values, transport equations, and receptor dose calculations to convey the relative magnitude of specific media occurrence, release probabilities, potential routes of uptake, and the ultimate impact on a human receptor.

The EPA Risk Assessment Guidance (RAG) document defines the following four elements for a completed exposure pathway (EPA, 1989b):

- A source and mechanism of chemical release to the environment
- An environmental transport medium for the released chemical (air, ground water, etc.)
- A point of potential human or biota contact with the contaminated medium (exposure point)
- A mode of uptake at the exposure point (ingestion, inhalation, or dermal contact).

If any of these elements are absent, there is neither human exposure nor risk. For the purposes of this assessment, the term exposure pathway will be used only when all four of these elements are present.

The risk assessment will be developed as follows:

Toxicity Assessment (Section 4.3)
The human health risks associated with radiation exposure are briefly described, with emphasis on exposure to plutonium.

Source Term (Section 4.4)
The source term describes the amount of contaminant (plutonium) found in the environment. For sites 200-202, the source term corresponds to plutonium concentrations in bottom sediments. The concentration of plutonium in the sediment affects the magnitude of any release into other media; for example, the lower the concentration of plutonium in sediment, the lower the airborne plutonium concentration that can be generated from the sediment.

Exposure Pathways (Section 4.5)
The importance of potential exposure pathways is assessed by estimating the magnitude of potential exposure, the frequency and duration of these exposures, and the media-specific pathways by which humans are potentially exposed. The magnitudes of potential exposures are based upon the media-specific (sediment) contamination being a contamination source for other media.

Exposure Routes (Mode of Uptake) (Section 4.6)
The various routes of plutonium uptake by humans and other organisms are identified and ranked by relative importance to the risk assessment. The risks associated with potential points of human contact are qualitatively assessed based on all identified exposure pathways. A description of the behavior of plutonium in biological systems is included in this section.

Risk Characterization (Section 4.7)

The concepts developed in preceding sections are combined into a site-specific risk characterization, which evaluates the concentration of plutonium in each media, its likelihood for transport to other media, and its likelihood to impact a human receptor. All potential exposure pathways are systematically examined, and those which do not meet the criteria of a completed pathway are eliminated from the risk assessment.

Exposure Point (Section 4.9)

The point of potential human contact with plutonium will be qualitatively assessed based on all completed exposure pathways identified in the risk assessment.

4.2 POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)

In the revised National Contingency Plan (NCP: 53 FR 51394) and the CERCLA compliance with other laws requirement (EPA, 1989c), several different types of ARAR requirements are identified with which remedial actions must comply: (1) chemical specific requirements, (2) action specific requirements, and (3) location specific requirements. The most stringent potential ARARs for plutonium are found in the Colorado Department of Health regulations. The site-specific soil ARAR identified for sites 200-202 is the CDH standard for plutonium in soil of 0.9 pCi/g (2 dpm/g). The CDH soil standard is exceeded in bottom sediments in a number of areas of Great Western Reservoir and Standley Lake. Mower Reservoir sediments have not been sampled but are believed to have similar concentrations of plutonium to those found in Great Western Reservoir and Standley Lake sediments (Section 2.3). The CDH standard was originally developed for protection of construction workers at sites containing plutonium contamination. Its applicability to buried lake sediments is as yet unclear. The Colorado Water Quality Control Commission has established a separate plutonium standard for Walnut and Woman Creeks of 0.05 pCi/l (0.002 Bq/l), significantly lower than the EPA standard of 15 pCi/l (0.56 Bq/l) total alpha activity. In addition, a CDH surface water plutonium standard exists for Great Western Reservoir and Standley Lake of 0.03 pCi/l (CDH, 1990a). All monitoring data reviewed indicate that the CDH plutonium limits for Walnut Creek, Woman Creek, Great Western Reservoir, and Standley Lake have never been exceeded. A Memorandum of Understanding and Mutual Cooperation Agreement between DOE and CDH regarding public exposure to airborne plutonium also exists. Offsite airborne levels of plutonium may not exceed 0.02 pCi/m^3 (0.0074 Bq/m^3) based on this agreement. All air monitoring data reviewed are well below this standard for air sample locations potentially impacted by sites 200-202. DOE Order 5400.5, Radiation Protection of the Public and the Environment, specifies the same airborne plutonium public exposure limit as the CDH (DOE, 1990). It is noted here, and discussed in Section 4.6, that the airborne standard is based on Class W (soluble) plutonium, while the majority of plutonium at sites 200-202 is Class Y (insoluble) plutonium, which has an ARAR of 0.04 pCi/m^3 (0.0015 Bq/m^3) (Wick, 1967).

4.3 TOXICITY ASSESSMENT

In order to evaluate the potential risks posed by plutonium, it is important to understand the toxicity hazards of radiation for different exposure routes. Radiation is defined as the transfer of energy from one place to another. Heat, sound, and light are radiation but typically do not carry enough energy to break the atomic bonds of molecules; however, ionizing radiation, when interacting with matter, has sufficient energy to break the atomic bonds of molecules, and produce (emit) an ejected electron and a positively charged ion. Ionizing radiation may be in the form of particles or electromagnetic waves.

Plutonium is primarily an alpha particle emitter. An alpha particle is essentially a helium nucleus without orbital electrons. It is composed of two protons and two neutrons with a charge of plus two. Since these alpha particles have a relatively large mass and +2 charge, they react strongly with matter, and create a large amount of ionization in a very short distance. However, even alpha particles with the high kinetic energies of plutonium travel only about 1.6 inches (4 cm) in air, and can be stopped by a piece of paper, or the outermost layer of dead skin. Alpha particles therefore do not present an external exposure hazard. These same properties do however produce much more cellular damage than an equivalent amount of gamma energy, if both alpha and gamma are internally deposited. The range of penetration of a plutonium alpha particle in tissue is approximately 100 microns (3.9×10^{-3} in), indicating that an alpha particle retained in the body will deposit

100 percent of its ionizing radiation to localized tissue. This section describes the various ways plutonium can enter the body (exposure routes), and the relative risk of each mode of uptake. It is likely that the insoluble form of plutonium, plutonium dioxide ($Pu0_2$), will be the predominant radionuclide available for biological uptake from sites 200-202, since the possibility of plutonium existing in another form in the reducing environment of buried sediments is remote. Even if a small percentage of the plutonium does exist in a more soluble form, the magnitude of risk determined in this qualitative assessment for the reservoirs will in fact remain the same.

In general, there are two distinct human hazards presented by radiation, those of external and internal radiation exposure. External radiation exposure is due mainly to gamma ray emissions from radioactive decay. Although plutonium does produce x- and gamma rays, they are very weak and only comprise a small percentage of the total energy emitted. Therefore, this risk assessment does not consider external radiation exposure (dermal contact) as a hazard from sites 200-202. Plutonium does, however, present an internal radiation hazard, primarily from inhalation. The inhalation of plutonium can lead to the deposition and retention of radioactivity in the lung, and produce continual, localized internal irradiation of lung and other body tissues for extended periods of time.

The levels of plutonium present in the sediment at sites 200-202 are very low, but have not been adequately characterized (Section 4.4). The health effects that this qualitative risk assessment will focus upon are the low levels of internal exposure that the public could potentially receive from sites 200-202, mainly by the airborne pathway. The National Academy of Science in a recently released report (NAS, 1990) has stated that such low levels of plutonium exposure can cause genetic and somatic (non-genetic, i.e. cancer) effects, which have a long latent period. These long-term effects are due to DNA damage. The body has many defense mechanisms against such damage, including repair of the DNA, immunological defenses, and the death of a cell. Ionizing radiation can also induce a neoplasm, the uncontrolled growth and proliferation of a group of cells (cancer).

4.4 SOURCE TERM

The initial step of this assessment involves evaluation of available source term data for sites 200-202. The source terms for the sites are considered to be plutonium buried in reservoir sediments outside the eastern boundary of the RFP. Historical radiological site data relevant to a human health evaluation were collected from DOE and CDH sources. These data were evaluated for the concentration of plutonium present in all media.

Representative sediment sampling has not occurred at sites 200-202. In some cases, the quantitation limits and detection limits for plutonium were not included in the referenced documents. It is believed that most of the published data have not been through a rigid QA/QC analysis. It is also evident that sampling procedures for all media have differed between various sampling agencies. Because of these uncertainties, a numerical value cannot be assigned to the source terms at sites 200-202 with any certainty since EPA guidance suggests using Level IV data for a risk assessment. Since the level of data quality is not discernable, a quantitative risk assessment cannot be performed. However, qualitative inferences concerning the source terms can be made. Section 4.14 discusses additional data needed for a reliable determination of IHSS 200-202 source terms to support a quantitative risk assessment.

4.5 EXPOSURE PATHWAYS

The identification and assessment of exposure pathways is accomplished by characterizing all potential contaminant release mechanisms which may contribute to a completed exposure pathway to human receptors. The release mechanism analysis evaluates the possible migration of the chemicals of concern, taking into account their physical and chemical properties that affect environmental fate in the various site media. Certain site characteristics such as hydrogeology, organic carbon concentration, climate, and vegetation may also significantly influence the migration potential. Current and future use of the site may determine the current and future exposure scenarios.

4.5.1 Identification of Release Mechanisms

Possible release mechanisms of plutonium from sediment at sites 200-202 are identified in the conceptual model shown in Figure 3-1. Primary release mechanisms include:

- Direct fugitive dust from sediments
- Wind stripping of water
- Reservoir discharge
- Drinking water withdrawal
- Infiltration/percolation
- Biotic uptake.

Figure 3-1 also includes an assessment of the secondary release mechanisms present at sites 200-202. These secondary release mechanisms include:

- Recreational use
- Direct fugitive dust from sediments
- Settled dust -- plants
- Settled dust -- soil (leading to possible airborne dust)
- Settled dust -- water
- Biotic uptake of surface water
- Surface water deposition
- Surface water irrigation
- Surface water infiltration
- Surface water evaporation/lowering (leading to possible airborne sediments)
- Ground water seepage
- Ground water pumpage
- Drinking water
- Precipitates from treatment plant.

4.5.2 Identification of Transport Media

A physical examination of sites 200-202 and an historical review of the records for the site indicate that the only primary transport media for plutonium is the contaminated sediments. Numerous possible primary release mechanisms are listed above, but it is the fugitive dust release mechanisms that can cause the greatest impact on the secondary transport media of air. Other potential transport media for plutonium include surface runoff, groundwater, and biotic uptake. The following discussion provides a more detailed description of soil reentrainment, and some description of the surface runoff, groundwater, and biotic uptake transport mechanisms.

4.5.2.1 Factors Affecting Airborne Reentrainment

An explanation of atmospheric transport parameters is presented in this section because inhalation of plutonium particles reentrained from exposed sediments is considered to be the most probable means of human exposure at sites 200-202. A receding shoreline may expose sediments containing plutonium, which can then become airborne. Shoreline variations are seasonal, and, thus although recession occurs, so does expansion and the net tends to be an average free-board over 70 years. The likelihood of a chronic release scenario resulting from this phenomena is dictated by (1) episodic drought occurrence and/or (2) population expansion placing an increased draw-down on the system without commensurate make-up. In addition, if the system is drawn down, natural processes will promote revegetation of the affected areas. It is therefore important to understand the mechanisms of contaminant transport before considering the corrective actions needed to reduce or eliminate transport.

Two primary mechanisms are associated with the initiation of particle movement. Direct action of air moving past a particle may exert enough force to accelerate the particle, causing it to roll along the surface or to be lifted up and moved in the air stream. A second mechanism of initiating particle movement is through the impact of airborne particles with particles on the ground. Particles on a solid surface which have chemical and physical properties different from the base material have adhesive contact with the substrate. For resuspension to occur with this scenario, the force on the particle must be equal to or greater than the force holding the particle to the surface. Several factors are known to influence particle cohesion:

- particle material
- size
- shape
- surface roughness
- relative humidity of the ambient air
- presence of electrostatic charge
- nature and physical characteristics of the substrate.

The primary meteorological factors which influence the resuspension of material from ground deposits are wind and ground surface moisture. The amount of material that can be carried in the air currents is dependent on the density, velocity, and viscosity of the air.

Particles that are dislodged from the exposed sediment material can then move in three ways: suspension, saltation, and surface creep. Suspension occurs when upward wind eddies counteract free fall, allowing transport of the particle at the average forward speed of the wind. These particles are generally less than 0.1 millimeter (mm) in diameter and are redeposited via rainout or gravity after the wind subsides. Particles between 0.1 mm and 0.5 mm in diameter move by a series of short bounces called saltation. Larger particles between 0.5 mm to 2 and 3 mm in diameter can roll and/or slide along the surface in what is called surface creep. Particle movement predominantly occurs by saltation.

Because of plutonium's strong affinity for clay in sediments, and because of the elapsed time since the last known releases to sites 200-202 (mid-1970s), it is likely that the plutonium become an integral part of the sediments, and will behave in exposed sediments according to the concepts developed for soil erosion. Among the parameters which most influence the movement of soil by wind are the space and time variations of the soil particle size distribution. Past studies have not determined what size fraction(s) of the sediments in sites 200-202 are affected by the plutonium, and it is not known what percentage of the plutonium might be available for deposition in the lung. The conservative assumption for this qualitative risk assessment is that, although very unlikely, all plutonium in the sediments is associated with particles of respirable size. The effect of this conservative assumption is that the characterization of risk resulting from this assumption will be overstated (i.e., the actual risk will likely be lower). To quantify the actual risk resulting from this pathway, sediment particle size (as well as other physical and chemical properties) would have to be evaluated.

4.5.2.2 <u>Plutonium Uptake in the Food Chain</u>

As described in Section 3.1.3, plutonium forms relatively insoluble compounds in the environment and is therefore not considered biologically mobile. This term describes the ability of an element to be transported through the food chain. Since plutonium has no known biological function, it can only be passively incorporated into organisms, mainly by physical processes such as surface contact, inhalation, and ingestion of plutonium adsorbed to the surfaces of plants and zooplankton.

Food-chain transfer of plutonium does represent a potential exposure route. A critical parameter used in this determination is K_{ow} (logarithmic octanol-water partition coefficient). This is a good indication of how readily an organism will take up a particular compound, and is a general predictor of bioaccumulation in the oils of fish or the fat of animals. The K_{ow} is related to water solubility and bioconcentration factors for aquatic and terrestrial life.

In an aquatic ecosystem, the supply of basic compounds such as carbon dioxide, and of elements such as oxygen, calcium, hydrogen, and nitrogen, is contained either in solution or is held in reserve in the bottom sediments. These nutrients are absorbed and metabolized through the utilization of solar energy by two main types of food producing organisms: rooted or large floating plants, and minute floating plants called phytoplankton. Available literature indicates that the plutonium K_{ow} for water and uptake of plutonium by terrestrial plants is extremely low, and that root uptake of plutonium is negligible (Rockwell, 1986).

As a general rule, radioisotopes present in sediments can pass into the root systems of plants in the same manner as nonradioactive isotopes of the same element. The element may or may not be required for normal metabolism, and some elements (e.g., iodine, cobalt, uranium, and radium) are known to be present in plants although they serve no metabolic function. However, even when plutonium is mixed into surface soil in a water-soluble form, it is strongly excluded from uptake in the first crop plants grown in that soil. The relative concentration factor expressed as parts per million in dry plant material/part per million in dry soil has been measured at less than 0.01% for plutonium (Menzel, 1965). This value has been replicated in a study of sheep grazing in a marsh estuary near Sellfield, England (Ham, 1989).

Radioactive substances can pass directly to the food chain by foliar deposition. The radionuclides may then pass directly to grazing animals or to man as superficial contamination, or they may be absorbed metabolically from the plant surface. The significance of plant surface contamination varies with the growing season, since the potential risk due to direct contamination of crops is obviously greater just before a harvest or during active grazing by stock animals. Conversely, the potential risk may be lowest in winter months when there are no standing crops, although it is possible that even during these months direct fallout on the basal structure of grasses in permanent pastures may be stored until the following spring. Retention of this type will be greatest for plants that develop a mat of basal parts, old stems, and surface roots.

The significance of foliar contamination of plants will also depend on the structure of the plants and the role of the various parts of the plant in relation to the dieting habits of man. Wheat plants have a shape that tends to maximize entrapment of settled fugitive dust. Other cereal grains and grasses also have relatively high foliar retention.

Foliar contamination can be removed by rain, other weathering effects, and by drying and dropping of plant parts (field loss). Chamberlain (1970) has examined data from a number of investigators and found the field loss during the growing season to be about 0.05 percent per day.

4.5.2.3 Surface Water

Because of plutonium's extremely low solubility and strong tendency to sorb onto suspended solids (Section 3.2), reservoir water at sites 200-202 are not likely to contain measurable amounts of plutonium unless contaminated bottom sediments become resuspended. This scenario has a low probability of occurrence, since the plutonium is buried in a discrete layer within the sediment. Routine monitoring of Great Western Reservoir and Standley Lake water quality consistently indicates very low to undetectable concentrations of plutonium, suggesting that significant resuspension of contaminated sediments does not occur at these reservoirs. Sampling procedures at these facilities would result in samples of "whole water" which contains any suspended sediment. Treatment procedures applied before the water enters the public distribution system include sedimentation and filtration which have the effect of removing suspended sediments. As discussed in Section 2.0, routine sampling and analysis conducted at the treatment facilities demonstrates that plutonium levels in the public water supply have always been below EPA water quality standards. The likelihood that this transport medium would produce an impact on a human receptor is negligible at sites 200-202.

4.5.2.4 Ground Water

As stated in Section 3.0, plutonium has an extremely low solubility in water and has a strong tendency to sorb to clays and other soil particulates. Previous studies have also determined that plutonium has a high affinity for clay in sediments, and that it is effectively immobilized in the clay-rich sediments typical of impoundments near the RFP (CSU, 1974). Other studies have found no evidence of plutonium migration through the sediment columns at Standley Lake and Great Western Reservoir (DOE, 1980). The information reviewed in Section 3.0 as well as the physical/chemical properties of plutonium substantiate the rationale that plutonium transport into the ground water system through infiltration/percolation and seepage bottom of the reservoirs is not a viable transport pathway.

4.5.3 Potential Exposure Pathways at sites 200-202

Potential exposure pathways will be addressed in this section. As illustrated in Figure 3-1, various possible transport media exist at sites 200-202 along with their associated primary and secondary release mechanisms. Section 3.0 describes the fate and mobility of plutonium in the environment, and concludes that plutonium is highly insoluble in ground water and surface water, and bonds strongly to particulates. As stated in Section 4.1, a completed exposure pathway must exist for a hazard to be conveyed to the receptor. Many of the potential transport media and release mechanisms identified thus far do not form a completed pathway, and therefore do not pose a risk to human health. However, the likelihood that fugitive dust from exposed sediments would be available for transport during the 70-year exposure scenario is remote. Nevertheless, this pathway will be retained. The only credible completed exposure pathway for sites 200-202 is shown in

Figure 4-1. Although other pathways are addressed for the sake of completeness, they are not considered in the determination of qualitative risk.

Primary and secondary release mechanisms are grouped with transport media (Table 4.1) to determine their probability of transporting plutonium in the environment over the duration of the exposure scenario (70 years) based on the following probability ranking:

1. High -- historic records or physical characteristics of sites 200-202 indicate that plutonium has a high probability of occurring in this release mechanism and/or transport medium

2. Moderate -- a possibility exists that plutonium may be released by this mechanism or transported by this medium

3. Low -- the likelihood is that this release mechanism or transport medium does not provide any significant possibility of release or transport in the environment

4. Negligible -- all historic data and physical characteristics of plutonium indicate that this is not a credible release mechanism or transport medium for plutonium.

4.5.3.1 Ground/Surface Water

With regard to water quality, the need for potential site remediation should be based largely on the evaluation of current and potential risks to the public who may use the reservoir or underground aquifer as a source of drinking water. A key evaluation criterion in selecting remedial measures at RFP should be the extent to which alternatives mitigate offsite exposure via the ground water/surface water pathway if in fact exposure is occurring. All data reviewed to this point indicates that the ground water/surface water interactions in and around all three reservoirs produce no detectable amount of plutonium in ground water. This conclusion is based on the premise that numerous RFP on-site wells are located in areas of documented contaminated pond leakage. In no case has the plutonium impacted ground water. If no impact is seen in this worst-case situation it is highly unlikely that the reservoirs will impact ground water.

All data reviewed indicates that ground water is not being impacted, and reservoir water quality data indicate that plutonium levels are far below regulatory limits. It is important to note that these levels are just above the analytical detection limit, and well below the

EPA or CDH risk-based limits of 15 pCi/l total alpha for drinking water. In the absence of data integrated over time, only a relative measure of purely hypothetical risk may be developed for the ground water/surface water exposure pathway. Based on the information presented in this document, the following conclusions can be drawn:

1. The sediments in all three reservoirs contribute little or no plutonium activity to ground water/surface water.

2. All sampling data from the reservoirs indicate that no bioaccumulation of plutonium is occurring in water plants, phytoplankton or fish.

3. Plutonium in sediments is essentially isolated from the water body due to the overlying sediment layer.

4. Plutonium rapidly and almost irreversibly attaches itself to clay sediments and there is no evidence of post-depositional migration of plutonium through the sediment. This leads to the conclusion that plutonium is not readily available for remixing in the water, even under lake turnover conditions.

5. All water quality monitoring data for plutonium in and around the reservoirs is at or below the analytical detection limits, and well below CDH and EPA regulatory standards.

6. Most importantly for receptor risk analysis, tap water samples taken from the communities that utilize the reservoirs as a source of drinking water indicate levels of plutonium just above or below the analytical detection limit, and well below the CDH and EPA drinking water standards.

Based on the above conclusions, the data suggest that there exists no appreciable risk under conditions of no action and thus no risk management alternatives involving remedial action would be required.

4.5.3.2 <u>Soil</u>

Much of the soil data reviewed indicate that natural processes such as biological activity, weathering and percolation will cause plutonium to move vertically downward in the top few centimeters of the soil column. Section 3.0 of this document also describes some of the factors most important to plutonium transport in buried lake sediments. One of the most important factors is the distribution coefficient (K_d). This term reflects the ability of ions and molecules to adhere to solid surfaces. The fine particles of soil and sediment have enormous surface areas relative to their volumes, and carry electric charges. Ions and molecules can bond to these surfaces by forces that range from those due to weak residual electric charges to strong chemical bonds. Typical K_d values (unitless) for plutonium are 10^3 to 10^5, indicating its high potential for immobilization by soil (Allard et al., 1983).

4.5.4 Reservoir Sediments

The most probable risk of exposure to plutonium from sites 200-202 is through the inhalation pathway. The areas of highest concentration of plutonium in Great Western Reservoir and Standley Lake appear to be in the deep water areas where the greatest sedimentation rates occur. The areas of minimum plutonium impact appear to be the shallow water and shoreline areas. These near-shore locations have the greatest potential to expose sediments to potential reentrainment into the atmosphere; however, since the plutonium concentrations are at or below the CDH ARAR for soil in these areas, the potential human risk via the inhalation pathway would be minimal. Based on the information presented in this document, the following conclusions can be drawn:

1. The highest plutonium concentrations tend to be in the deepest parts of the reservoirs. This conclusion has not been definitively proved for Standley Lake and Mower Reservoir.

2. The lowest plutonium concentrations tend to be along the shoreline and shallow water areas of the reservoirs.

3. Sediment sampling results indicate that discrete contamination layers exist at both Standley Lake and Great Western Reservoir, and have been buried by subsequent sedimentation.

4. The plutonium is strongly bound to the sediments and will not readily dissolve or migrate through the sediment column.

5. It is possible that the reservoir levels may drop, exposing plutonium-containing sediments to drying; however, in general, this exposed beach area would produce a crusty, platelike surface which would require pulverization for the sediments to become airborne. It is plausible that vehicular traffic could produce this pulverization. If reservoir levels remain low, long-term weathering could also eventually provide means for reentrainment.

Although this pathway is the only credible one for sites 200-202, it has a low probability of significant occurrence. Based on the above conclusions, it is determined that the no-action alternative for the sediment inhalation pathway presents a low hazard to the public, and should therefore be retained in the risk assessment.

4.6 EXPOSURE ROUTES

Various modes of uptake, including inhalation, ingestion, and dermal contact, can lead to internal radiation exposure. The two primary modes of plutonium uptake that would lead to internal radiation exposure are the inhalation and ingestion of radioactive materials. Dermal contact is not a significant mode. The estimation of organ burden and exposure, as well as of the resulting dose rates and doses, due to uptake by these pathways is based on the use of mathematical models which depend on many parameters. Publications ICRP 30 (ICRP, 1979), ICRP 31 (ICRP, 1980), and ICRP 48 (ICRP, 1986) provide the criteria necessary to calculate the committed effective dose equivalent for both occupational workers and the general public. This section will show that the risk associated with the dermal contact and ingestion exposure routes is insignificant when compared to inhalation.

4.6.1 Inhalation

The inhalation of an aerosol carrying radionuclides is a potential mechanism for damage to the respiratory tract as well as a possible exposure route for the translocation of inhaled radioactive material to other reference organs. The complexity of the biological phenomena which govern transmission and elimination of such material complicates the assessment of potential health effects due to inhalation of radioactive material. Factors which must be included are:

1. The fractional deposition of inhaled material in the respiratory tract depends on properties of the aerosol size and mass distribution, chemical form, and charge, as well as on the breathing rate and such physiological characteristics of the lung as its surface properties and configuration. For the purposes of this qualitative risk assessment, it is assumed that 100 percent of the plutonium is available for uptake. In the quantitative risk assessment this assumption will be refined based on further evaluation.

2. The duration and extent of the exposure depends on the biological and physical mechanisms which transport the deposited material and its decay products within

the body. These include the various clearance paths, the nuclide half-lives, the chemical form, the solubility, and the degree of retention in each reference organ of interest.

3. The dose depends on the time integrals of the activity of both parent and daughter in the organ, the organ mass, the emitted energy of each nuclide, and the fraction of that energy absorbed by the organ tissues.

Inhalation is the most common exposure route by which plutonium can cross the barriers of the body and penetrate into and across living cells. The aerodynamic particle size of the aerosol, which accounts for not only the sizes of the particles but also their density and shape, determines the fractional deposition and sites of deposition in the respiratory tract. The bioavailability of plutonium adsorbed to particles often depends on this aerodynamic particle size. Particles with a diameter greater than 5 micrometers usually become imbedded in the mucous of the pharynx, trachea, or bronchi. The mucous is swept up the respiratory tract and swallowed. The absorption efficiency of these large particles depends on the gastrointestinal absorption efficiency, which is extremely low for plutonium (Section 4.6.2). Consequently, inhaled particles that are subsequently ingested reduce the risk associated with the inhalation exposure route. The subsequent rates and routes of clearance, the translocation to, deposition in, and rate of clearance from other tissues, and the excretion in urine and feces of plutonium depend on particle size, solubility, density, shape, and other physicochemical characteristics of the plutonium aerosol. The biological half lifes in the lung are defined for various solubility classes as Days (0.5 days), Weeks (50 days) and Years (500 days). The ICRP has determined the solubility class for various plutonium compounds (ICRP, 1979). These are:

- Class D (days) - no plutonium compounds
- Class W (weeks) - all plutonium compounds except plutonium dioxide (PuO_2)
- Class Y (years) - plutonium dioxide (PuO_2)

4.6.2 Ingestion

The ingestion of radioactive material represents another exposure route by which radioactivity may be transferred internally to blood and, subsequently, to other organs. While a description of this route is simpler than for inhalation, due to the direct deposition of the ingested material into the gastrointestinal (GI) tract, treatment of the balance of the biological-physical processes involved is affected by the same uncertainties of biological parameters as were discussed for the inhalation model. In the ingestion model the critical transfer mechanism is the absorption of radioactive material into the systemic blood from the small intestine. However, the gastrointestinal tract provides a substantial barrier to the uptake of plutonium ingested with food or water. Inhaled plutonium will also be cleared from the lungs to the gastrointestinal tract, so gastrointestinal absorption is a consideration, although it is a negligible pathway in regards to risk. Values for the fraction, F_1 (GI absorption factor), of ingested radioactivity transferred to blood have been published. The DOE lists an F_1 value of 1.0 E-05 for Class Y plutonium-239 (DOE, 1988). This indicates that the ingested plutonium will not easily transfer to other body compartments. Class Y plutonium refers to the solubility and body retention of the radionuclide. If ingested, Class Y plutonium tends to pass through the body with insignificant biological uptake. As stated previously, PuO_2 is considered to be insoluble in the body, and thus is classified as Class Y plutonium. This qualitative risk assessment makes the assumption that the amount of Class W plutonium (more soluble in the body) is negligible when compared to the amount of Class Y plutonium found at sites 200-202 (DOE, 1988).

4.6.3 Dermal Contact

Plutonium-239 and plutonium-240 are alpha emitters and hence only present a biological hazard if they are transferred into a biological system. The dermal contact exposure route for plutonium would involve skin contamination and subsequent transfer into the body through an open wound or by ingestion. Unbroken skin has been shown to be an effective barrier to the penetration of plutonium, and dermal absorption coefficients cited in the literature are on the order of 5×10^{-5} (NRC, 1988). It is highly unlikely that soluble plutonium is present at sites 200-202 in a concentration that would lead to transfer through an open wound by skin contamination. Since the GI absorption factor is 1.0×10^{-5} for class Y (insoluble) plutonium, human biouptake of plutonium sediment by the dermal contact exposure route and subsequent GI absorption is not plausible.

These risk values are restated here to reinforce that the inhalation exposure route produces by far the principal hazard from sites 200-202. Because of plutonium's low soil mobility and water insolubility, the health risk associated with plutonium ingestion is insignificant when compared to the health risk associated with plutonium inhalation.

4.7 RISK CHARACTERIZATION

A qualitative risk assessment is a systematic identification of potential hazards of events that could result in undesirable consequences, and is basically subjective. The main disadvantage of a qualitative approach is that it is difficult to make specific numerical comparisons among the risks of different events or scenarios. However, as shown in Table 4.1, hazards can be grouped by relative importance into risk categories (i.e., critical, marginal) and linked with frequency categories (i.e., high, moderate, low, negligible). Pathways and release mechanisms that have a critical importance to the risk assessment have a high probability of impacting a human receptor. Those that have a marginal importance have a very low probability of impacting a human receptor.

4.7.1 Risk Characterization Process

The risk characterization presented here evaluates the concentration of plutonium in each medium, its likelihood for transport to other media, and its likelihood to impact a human receptor. The concepts developed in preceding sections are utilized to determine the magnitude of risk based on the following ranking:

1. High -- An appreciable potential unacceptable risk to human health exists based on historical data, physical characteristics and/or present conditions.

2. Moderate -- It is conceivable that plutonium exposure could occur at the receptor point by using maximum credible scenario assumptions.

3. Low -- It is highly unlikely that an unacceptable risk to human health exists, using maximum credible assumptions of release mechanisms and exposure pathways combined with historical data, the physical characteristics of plutonium transport, and present conditions.

4. Negligible -- The release mechanisms and completed exposure pathways do not exist to constitute an unacceptable risk to human health.

4.7.2 Physical Model

Providing a reasonable estimate of internal radiation doses due to inhalation and ingestion requires that a consistent model for both the respiratory and gastrointestinal tracts be employed. While a large amount of theoretical and experimental work on such models has been done, the most widely accepted models that provide reasonable estimates of internal radiation doses have been those developed by members of the respective ICRP working groups.

The proposed ICRP Task Group on Lung Dynamics (TGLD) model for the respiratory tract has been well documented. Parameters suggested for use in the model have been extensively reviewed and, to some extent, improved in ICRP publications (ICRP, 1979; ICRP, 1980). The ICRP TGLD proposed model incorporates three major respiratory compartments: the nasopharyngeal, the tracheobronchial, and the pulmonary. Each of these major compartments is divided into subcompartments corresponding to various transfer mechanisms, which are treated as essentially independent processes. In addition, the associated lymph nodes are appended to the pulmonary compartment in one of the transfer chains. Direct deposition through inhalation occurs to the three major compartments, with the fractional deposition in each being a function of the aerosol properties. Subsequent transfer and/or clearance is governed by parameters specified for each subcompartment.

The ICRP gastrointestinal tract model can also be used to calculate internal exposure as a result of radioactive contaminant ingestion. The model comprises a four-compartment tract consisting of the stomach, small intestine, and lower and upper large intestine. The times involved in the passage of material through the stomach and small intestine (the only compartment from which transfer into the blood occurs) are negligible compared to the residence times associated with most Class Y compounds in the lung and can be neglected when considering doses due to ingestion of insoluble plutonium.

4.7.3 Risk From All Modes of Exposure

The various chemical forms of plutonium are highly insoluble both in the environment and in the human body. Based on a review of exposure durations and modes, it appears that the dose equivalent is negligible and poses a very low risk pathway in the qualitative model. Developing these concepts in tabular form, biological uptake mechanisms from all release pathways can be ranked from most likely to least likely:

Exposure Route

- Inhalation
- Inhalation then ingestion
- Ingestion of sediment
- Bioaccumulation
- Dermal contact
- Ingestion of drinking water.

The last five routes are considered negligible from a risk standpoint. In lieu of performing a calculation based on the concepts of Section 4.6, a qualitative comparison of pathway specific risk is provided by the EPA (EPA, 1990). The EPA has developed the following media-specific concentration-based unit risk factors for age-averaged lifetime excess total cancer per unit daily intake (exposure for 70 years) of Class Y plutonium-239:

	Air 1 pCi/m^3	Drinking Water 1 pCi/L	Soil Ingestion 1 pCi/g
Cancer Risk Factor[1]	2.6 E-2	1.6 E-6	8.4 E-8

[1] The media-specific risk factors are based on standard man (155 lbs [70 Kg]) intake rates of:

- 706 ft^3/day (20 m^3/day) inhaled air
- 0.6 gal/day (2.2 l/day) ingested liquid
- 2.2 x 10^{-4} lbs/day (0.1 g/day) ingested soil.

These values assume that all daily media exposure is derived from contaminated airborne fugitive dust (706 ft^3), surface water/surface runoff (0.6 gal water), and soil (2.2 x 10^{-4} lbs) and that exposure occurs continuously for a 70-year lifetime.

To assess the cancer risk of exposure to an environmental pollutant such as plutonium, three pieces of information are requested: (1) the carcinogenic potency (unit risk factor) of the pollutant being considered, (2) an estimation of the airborne concentration that people may breathe, and (3) an estimation of the number of people exposed to those concentrations. The unit risk factor is a quantitative estimate of the carcinogenic potency and is expressed as the chance of contracting cancer from a 70-year lifetime continuous exposure of 1 pCi/m^3 of a given radionuclide for the airborne pathway. The unit risk factor listed for the air pathway is 2.6 E-02 (pCi/m^3). This indicates that an estimated 2.6 excess cancers per 100 people exposed would develop if this group were exposed to 1 pCi/m^3 of plutonium for 70 years. At this airborne concentration an unacceptable risk to humans would be produced. However, the air monitoring data reviewed indicate no discernable increase in airborne plutonium levels downwind from Sites 200-202. The natural background risk of cancer death is approximately 2E-01. This indicates that given a group of 100 people approximately 20 will die from cancer. The additional risk, if any, cannot be calculated given the limits of this qualitative risk assessment, but can be determined in a quantitative assessment. However, the added risk of plutonium exposure from Sites 200-202 is negligible.

These unit risk factors use the same basic approach as other models (DOE, ICRP); however, the EPA uses the model to derive risk from each type of media. These risk factors reinforce the premise that inhalation of plutonium (pCi/m^3) has a much greater risk factor than from ingestion of water (pCi/l) or soil (pCi/g). Since it has been shown that the air pathway from sites 200-202 produces a negligible risk to the public, all other pathways must also produce a negligible risk.

4.8 APPLICATION OF RISK ASSESSMENT TO EACH RESERVOIR

The reservoirs have been treated as a single unit because of the similarities of source term (plutonium), a single potentially significant exposure pathway (fugitive dust from sediment drying), and a single potentially significant exposure route (inhalation). The final criteria, that of exposure point, is somewhat different for each of the three reservoirs. The following section will restate the source term, exposure pathway, exposure route, and exposure point for each reservoir separately.

4.8.1 Great Western Reservoir

Until recently, Walnut Creek emptied into Great Western Reservoir, which is the drinking water source for the City of Broomfield. At full capacity, this reservoir is a maximum of 62 ft (19 m) deep and covers 7.2×10^6 ft^2 (668,000 m^2) with a volume of 1.2×10^8 ft^3 (3,430,000 m^3). Except during periods of heavy rain and runoff the reservoir is not filled to capacity. More typically, the reservoir is maintained at about 43 ft (13 m) depth covering an area of 3.2×10^6 ft^2 (294,500 m^2) with a volume of 4.1×10^7 ft^3 (1,162,000 m^3) (Thompson, 1975).

Public access to the reservoir is restricted, and no recreational use of it is allowed. Historical data indicates that the source of plutonium present in the reservoir is from waste liquid discharges from holding ponds that were transported to the reservoir via Walnut Creek. This pathway has been eliminated (Section 2.1). It is unclear if some fraction of the plutonium present in the reservoir sediments is from the airborne pathway produced by the 903 Pad barrel storage area in the RFP main production facility. However, this source also has been eliminated by remedial action (removal of contaminated soils) and institutional controls (construction of an asphalt pad) (Krey and Hardy, 1970).

4.8.1.1 Surface Water/Tap Water/Ground Water

All of the reservoir, domestic water, and background water quality results for Great Western Reservoir are essentially the same within the limits of analytical and sampling variations. The results indicate that the sediment in the reservoir is effectively immobilizing the plutonium and preventing its movement into municipal drinking water. The reservoir water passes through a filter prior to domestic consumption, greatly reducing the likelihood that suspended silt containing plutonium could reach a receptor through the drinking water pathway. The silt is sampled for plutonium and all data indicate that plutonium concentrations are just above or at analytical detection limits. An extensive ground water monitoring system on and around the RFP has been developed. The well locations were selected to intercept ground water in areas where potential contamination might be expected. Well locations are near holding ponds, evaporation ponds, and creek beds. Monitoring wells in the buffer zone along the eastern boundary of the RFP have been sampled, and in no case has plutonium above background levels been detected. Although data are not available concerning plutonium transport from Great Western surface water/sediments to ground water, it can be inferred that this pathway is not plausible. This suggests that soil/sediment is a good medium for removing plutonium from an aqueous media. Since surface water, ground water, and tap water are not release mechanisms for plutonium transport in the environment, the following pathways can be discounted for Great Western Reservoir in this qualitative risk assessment:

Surface Water → Tap Water
Surface Water → Ground Water
Surface Water → Biotic Uptake
Surface Water → Deposition
Surface Water → Irrigation
Surface Water → Infiltration
Surface Water → Fugitive dust wind erosion
Ground Water → Seepage
Ground Water → Pumpage

Populations using the reservoirs for water consumption are not ingesting plutonium concentrations in excess of CDH or EPA water quality criteria.

4.8.1.2 Reservoir Sediments

Sediment sampling has been performed at Great Western Reservoir on a number of occasions (Section 2.1). The highest concentrations of plutonium were found near the inlet of the reservoir and along the dam where the greatest sedimentation rate has also been measured. Subsequent sedimentation has buried the plutonium in a layer approximately 12-15 inches below the top of the sediment. Since it is possible that under normal conditions the reservoir level could drop and expose potentially contaminated shallow water sediments for subsequent fugitive dust wind erosion, this pathway will remain in the qualitative risk assessment.

4.8.1.3 Spillway Sediments

Spillway sediment plutonium concentrations have been measured at Great Western Reservoir, and the results indicate that sediments accumulating within the spillway were well below the 2 dpm/g (0.033 Bq/g) activity screening level adopted by CDH (Rockwell, 1980). During periods when the reservoir is not at maximum capacity, the sediment in the spillway is not submerged. The location of greatest depth of sediment is near the stop logs of the entrance and sediment accumulation is at minimum at the southeast end of the spillway. Although it is possible that these sediments could be the source of fugitive dust, the levels are below applicable ARARs. Therefore the

Lake/Reservoir Sediments → Reservoir Discharge → Surface Water → Fugitive Dust

pathway can be discounted for Great Western Reservoir in this qualitative risk assessment.

4.8.1.4 Air

No credible scenario exists that could produce an exposure pathway from wind stripping of the surface water. As stated previously, routine water quality monitoring at Great Western Reservoir indicates that reservoir water is not significantly impacted by plutonium. Therefore, the following pathway can be discounted for Great Western Reservoir in this qualitative risk assessment:

Wind Stripping of Water → Air

4.8.2 Standley Lake

Standley Lake is a large body of water 43,000 acre-ft (5,300 hectare-meter) in volume, located approximately 2 miles (3.2 kilom) southeast of RFP's eastern boundary. The reservoir is used as a part of the municipal water supply for the cities of Westminster, Northglenn and Thornton, and is capable of supporting approximately 185,000 persons. In addition, the reservoir serves as a recreation area. Boating, fishing, swimming, hiking and biking occur in and around the reservoir.

Standley Lake receives approximately 95 percent of its water from Clear Creek via an irrigation ditch, a water source that has no history of plutonium transport. Woman Creek, an ephemeral stream which also feeds Standley Lake, has been a pathway by which plutonium could migrate to the reservoir. Historical data indicates that other likely pathways are soil erosion within the Woman Creek watershed and windblown plutonium contamination from the 903 Pad area. The airborne source has been eliminated by remedial action (removal of contaminated soils) and institutional controls (construction of an asphalt pad). Although the surface water-soil erosion pathway may conceivably still exist, studies of Standley Lake sediments indicate that contamination is not ongoing.

4.8.2.1 Surface Water/Tap Water/Ground Water

All of the reservoir, domestic water, and background water quality results for Standley Lake are essentially the same within the limits of analytical and sampling variations. The results indicate that the sediment in the reservoir is effectively holding the plutonium and preventing its movement into municipal drinking water. The reservoir water passes through a filter prior to domestic consumption, greatly reducing the likelihood that suspended silt containing plutonium could reach a receptor through the drinking water pathway. Extensive ground water monitoring wells on and around the RFP have been developed. The well locations were selected to intercept ground water in areas where potential contamination might be expected. Well locations are near holding ponds, evaporation ponds, and creek beds. Monitoring wells in the buffer zone surrounding the RFP have also been developed, and in no case has plutonium above background levels been detected. This suggests soil/sediment is a good medium for removing plutonium from an aqueous media. Although data are not available concerning plutonium transport from Standley Lake surface water/sediments to ground water, it can be inferred that this pathway is not plausible. Therefore, since surface water, ground water, and tap water are not release mechanisms for plutonium transport in the environment, the following pathways can be discounted for Standley Lake in this qualitative risk assessment:

Surface Water → Tap Water
Surface Water → Ground Water
Surface Water → Biotic Uptake
Surface Water → Deposition
Surface Water → Irrigation
Surface Water → Infiltration
Surface Water → Fugitive dust wind erosion

Ground Water → Seepage
Ground Water → Pumpage

4.8.2.2 Reservoir Sediments

Plutonium concentrations in Standley Lake sediments are much lower than those found at Great Western Reservoir. However, this conclusion is based on limited sampling data. This source of release to the environment will remain as a potential pathway in the qualitative risk assessment since it is possible that lake levels will decrease, exposing sediments potentially containing plutonium. These sediments could then create fugitive dust through wind erosion.

4.8.2.3 Air

No credible scenario exists that could produce an exposure pathway from wind stripping of the surface water. As stated previously, routine water quality monitoring at Standley Lake indicates that reservoir water is not significantly impacted by plutonium. Therefore, the following pathway can be discounted for Standley Lake in this qualitative risk assessment:

Wind Stripping of Water → Air

4.8.2.4 Biota

Since Standley Lake is used as a recreational resource for fishing, the Colorado Department of Health analyzed edible fish tissue collected from the lake for the presence of plutonium (CDH, 1990c). Bottom feeders, mid-level and surface predator fish were captured, and in all cases, plutonium concentrations in tissue from all species of fish sampled were at or below the lower limit of detection for this analysis. Since fish represent the highest level of organisms within the food chain in Standley Lake (excluding fish-eating birds and humans), this lack of plutonium indicates that bioconcentration of plutonium is not moving up the food chain at Standley Lake.

4.8.3 Mower Reservoir

Very little documentation exists for Mower Reservoir. The reservoir is used for agricultural purposes and has restricted public access. No recreational use of the reservoir is known to exist. Because it is fed by a diversion from Woman Creek, this reservoir may have been affected by the surface water contaminants believed to have contributed to plutonium levels in Standley Lake sediments (Section 2.2). Plutonium from contaminated soils around the reservoir (IHSS 199) may impact Mower Reservoir, but because current plutonium levels are so low at IHSS 199, it is believed that any future impact will be negligible. It has been speculated that concentrations of radionuclides in Mower Reservoir sediments should not exceed levels measured in Great Western Reservoir and Standley Lake. Therefore, the same description of possible pathways and their exclusion from the risk model will be restated here.

4.8.3.1 Surface Water/Tap Water/Ground Water

No information is available concerning plutonium concentrations in Mower Reservoir water. It is assumed for purposes of this risk assessment that the same processes which hold plutonium in bottom sediments and prevent contamination of reservoir water in Standley Lake and Great Western Reservoir also occur in Mower Reservoir. Mower Reservoir is not used as a source of drinking water, so cannot impact human receptors through consumption of tap water. The following pathways can therefore be discounted for Mower Reservoir in this qualitative risk assessment:

Surface Water → Tap Water
Surface Water → Ground Water
Surface Water → Biotic Uptake
Surface Water → Deposition
Surface Water → Irrigation
Surface Water → Infiltration
Surface Water → Fugitive dust wind erosion
Ground Water → Seepage
Ground Water → Pumpage

4.8.3.2 Reservoir Sediments

No information is available concerning plutonium concentrations in Mower Reservoir sediments. It is possible that reservoir levels will decrease, exposing sediments potentially containing plutonium. These sediments could then create fugitive dust through wind erosion. Since plutonium concentrations in these sediments are potentially similar to those found in Great Western Reservoir or Standley Lake, the reservoir sediment/air pathway will remain as a potential pathway in the qualitative risk assessment.

4.8.3.3 Air

As stated in Section 4.8.3.1, it is assumed that the same processes which prevent contamination of reservoir water in Standley Lake and Great Western Reservoir also occur in Mower Reservoir. It is considered highly unlikely that Mower Reservoir water could contain significant amounts of plutonium-contaminated suspended solids available for wind stripping from the reservoir surface. Therefore, the following pathway can be discounted for Mower Reservoir in this qualitative risk assessment:

Wind Stripping of Water → Air

4.9 POPULATIONS AT RISK OF EXPOSURE

In a quantitative risk assessment, all media-specific pathways would be quantified as to the potential exposure, and then applied to all types of populations. Commercial, residential, and recreational use of the land changes the type and duration of each of these exposure pathways, and greatly affects the numerical result of the risk assessment.

The inherent uncertainty of a qualitative risk assessment does not lend itself to this type of detail when examining populations at risk and various land use scenarios. The source, pathway analyses and release mechanisms indicate airborne inhalation of fugitive dust is the only significant potential pathway from sites 200-202. The population distributions (residential) of the 0-5 mile (0-8 kilometer) and 10-50 mile (16-80 kilometer) radius sectors from the center of the RFP are provided in Figures 4-2 and 4-3, respectively, with wind rose overlays indicating measured wind directions, speeds and frequencies. The wind rose shows that the prevalent wind direction is to the east, east-southeast and south-southeast. Typical wind speeds range from 10-50 ft/sec (3-15 m/sec), with infrequent continuous speeds above 50 ft/sec (15 m/sec).

It is extremely difficult to provide any meaningful description of the populations at risk of exposure in a qualitative risk assessment. The wind rose/population descriptions presented in Figures 4-2 and 4-3 provide some indication of the magnitude of potential exposure. A trend in quantitative risk assessment is to measure the concentration of a contaminant of concern in all media sources, and then model exposure at the receptor point using maximum credible scenarios. All pathways described in this report could be assigned a numerical concentration value, and committed effective dose equivalent from the plutonium present at sites 200-202 could be calculated. Population committed effective dose could also be calculated by sector using this model.

4.10 UNCERTAINTIES IN THE RISK EVALUATION

The procedures and inputs used to assess potential human health and environmental risks in this and most such evaluations are subject to a wide variety of uncertainties. The five main sources of uncertainty are the following:

- Inadequate sample population
- Sampling and analytical methods
- Fate and transport modeling
- Exposure estimation
- Toxicological data and dose response extrapolation.

Errors associated with sampling and analysis include inherent errors in laboratory analysis, representativeness of the samples, sampling errors, and heterogeneity of the sample matrix. Although QA/QC programs serve to reduce these errors, they cannot eliminate all errors associated with sampling and analysis.

Toxicological data errors are probably the largest source of uncertainty. The EPA noted this in its guidelines for carcinogenic risk assessment:

> "There are major uncertainties in extrapolating both from animals to humans and from high to low doses. There are important species differences in uptake, metabolism, and organ distribution of carcinogens, as well as species and strain differences in large site susceptibility. Human populations are variable with respect to geographic constitution, diet, occupational and home environment, activity patterns and other cultural factors" (EPA, 1986).

The estimation of exposure requires numerous assumptions to describe the potential exposure situations. There are a number of uncertainties regarding the fate and transport of plutonium, the likelihood of exposure, the frequency of contact with contaminated media, the concentration of constituents at exposure points, and the time period of exposure. These assumptions tend to oversimplify actual site conditions. There are inherent uncertainties in determining the intake value when combined with toxicological information, to assess risk. In this qualitative assessment, specific assumptions with standardized values were used. The major assumptions used in this assessment are as follows:

- Constituent concentrations remain constant over the exposure period
- Exposure remains constant over time
- Average concentrations of constituents detected are reasonable estimates of exposure at the exposure point
- Exposed populations remain constant over the exposure period
- No dilution factor for the contaminants is offered, and they are available for 100 percent biouptake
- Risks are additive.

Table 4.2 qualitatively describes the general assumptions used in the risk assessment, and the effects of each on the risk assessment.

4.11 DATA NEEDS

It is evident that sufficient validated field data are lacking to perform a quantative risk assessment of IHSSs 200-202. The following quantitative information would greatly increase the accuracy of any future risk assessment. Many of the data needs listed below have been acquired for the holding ponds and meteorological conditions at the RFP site; the applicability of the existing data to sites 200-202, however, has not been evaluated, and much of the existing data have not been validated. The first step in the data acquisition process, therefore, should be to evaluate the applicability of existing environmental data from the RFP to sites 200-202.

4.11.1 Physical Parameters of the Site

Sediment parameters such as particle size, determination of sediment particle size fraction with which plutonium is associated, organic content, and bulk density should be determined. Meteorological parameters such as the frequency distribution of windspeed, direction and annual stability class should be collected. Maximum credible sediment and meteorological conditions (i.e., those conditions at each site most conducive to plutonium transport) should be identified and calculated.

4.11.2 Radiological Characterization

The distribution and magnitude of all plutonium and americium concentrations in sediments at all three reservoirs should be determined. Sediment sampling should be conducted at Mower Reservoir to characterize the sediment column and assess the impact of past RFP releases on the reservoir. Sediment samples should be collected at Great Western Reservoir and Standley Lake. A standardized sampling procedure should be developed for the quantitative risk assessment. Additional sediment cores should be collected to determine the vertical migration of plutonium in the sediment column. Data collection should focus on those areas most likely to be exposed to drying and possible fugitive dust generation from sediments (i.e., shallow, near-shore areas).

5.0 CONCLUSIONS AND RECOMMENDATIONS

Over thirty documents detailing studies of sites 200-202 were reviewed in preparing this report. These studies address different aspects of the sites and have been conducted using markedly different techniques. While this inconsistency in approach and technique has limited the usefulness of the collective data relative to IAG requirements, the following conclusions can be drawn from the body of available information for sites 200-202:

- The concentrations of plutonium in the sediments in areas of highest exposure potential (i.e., near-shore areas) of Great Western Reservoir and Standley Lake are above background, but are below the CDH guideline for plutonium in soil of 0.9 picocurie per gram (pCi/g) (0.03 becquerel per gram (Bq/g)). The data supporting this conclusion, however, have not been validated.

- No data have been collected to assess plutonium concentrations in Mower Reservoir sediments. Because general site conditions and contaminant sources for Mower Reservoir appear similar to those for Great Western Reservoir and Standley Lake, it is expected that Mower Reservoir sediment plutonium concentrations are not significantly different than those in Great Western Reservoir and Standley Lake.

- Of the ten potential exposure pathways identified for the reservoirs, the airborne pathway from reentrainment of exposed sediments is the only credible pathway that will convey plutonium to human receptors from sites 200-202.

- Airborne plutonium concentrations measured by air monitors downwind of sites 200-202 have remained well below the 0.02 pCi/m^3 (0.0007 Bq/m^3) standard set by CDH.

- Residential tap water derived from Standley Lake and Great Western Reservoir is routinely analyzed for plutonium. Results consistently indicate that plutonium concentrations are well below CDH drinking water standards.

- Plutonium is strongly adsorbed to the clay-rich sediments typical in impoundments near the RFP. Studies have shown that plutonium in the reservoir sediment columns is effectively immobilized.

While the available data for sites 200-202 point to the above conclusions, they are not sufficient to support a quantitative risk assessment. To confirm these conclusions with quantitative data, it is recommended that additional site data, including meteorological parameters and sediment and air samples be collected. Further sediment sampling should be performed to confirm conclusions concerning plutonium concentrations and mobility in sediments at sites 200-202. A quantitative risk assessment can then be performed to quantify the human health risks associated with the three reservoirs. These data collection activities should be integrated into future Remedial Investigation activities.

6.0 BIBLIOGRAPHY AND LIST OF REFERENCES

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TABLE 2.1
DATA SOURCES, SITES 200 - 202, ROCKY FLATS PLANT

The following table is keyed to the Bibliography and List of References in Section 6.0.

GREAT WESTERN RESERVOIR	
Data Source	Nature of Data
Battelle, 1974	Plutonium and americium concentrations measured in 1974 in Great Western Reservoir and Walnut Creek sediments, and in Broomfield tap water
Dow, 1973b	Summary of RFP sanitary sewer releases possibly affecting the Walnut Creek drainage within the RFP
CSU, 1974	Plutonium concentrations measured from 1971 - 1974 in Great Western Reservoir sediments
DOE, 1980	Comprehensive summary of analytical data obtained prior to 1980 for Great Western Reservoir and Walnut Creek water and sediments
Dow, 1974	Summary of selected radionuclide concentrations measured in 1973 by EPA and CDH in Great Western Reservoir sediments
EPA, 1975	Plutonium concentrations measured in 1973 in Great Western Reservoir sediments--also includes plutonium concentrations measured in 1974 in sediments of several Front Range reservoirs believed to be unaffected by releases from the RFP
EPA, 1974	Documentation of 1974 RFP tritium release affecting Walnut Creek and Great Western Reservoir
EPA, 1973	Plutonium and uranium concentrations measured in 1970 in Great Western Reservoir and Walnut Creek sediments and water (uranium data for water only)
Rockwell, 1988b	Summary of plutonium concentrations in Great Western Reservoir sediments
Rockwell, 1986a	Summary of selected radionuclide concentrations in Great Western Reservoir and Walnut Creek water, in municipal tap waters around the RFP, and in Great Western Reservoir sediments
Rockwell, 1985a	Plutonium concentrations in surface soils north, west and south of Great Western Reservoir
Rockwell, 1985b	Plutonium concentrations measured in 1983 in Great Western Reservoir sediments
Rockwell, 1981	Plutonium concentrations in Great Western Reservoir water and tap water in communities around the RFP

TABLE 2.1
DATA SOURCES, SITES 200 - 202, ROCKY FLATS PLANT
(continued)

GREAT WESTERN RESERVOIR	
Data Source	Nature of Data
Rockwell, 1980	Plutonium and americium concentrations in sediments on the Great Western Reservoir spillway
Rockwell, 1979	Plutonium and americium concentrations in sediments on the Great Western Reservoir spillway
Thompson, 1975	Summary of selected radionuclide concentrations measured by various agencies prior to 1975 in Great Western Reservoir, Walnut Creek, and municipal tap waters around the RFP
Thompson, 1973	Summary of selected radionuclide concentrations measured in 1973 by various agencies in Great Western Reservoir sediments

STANDLEY LAKE	
Data Source	Nature of Data
Battelle, 1974	Plutonium and americium concentrations measured in 1974 from a single sediment core from Standley Lake
CDH, 1990b	Concentrations of selected radionuclides and nonradioactive contaminants in various species of fish collected from Standley Lake
DOE, 1980	Comprehensive summary of analytical data obtained prior to 1980 for Standley Lake and Woman Creek water and sediments
DOE, 1978	Cesium-137 and transuranic radionuclide concentrations measured in 1976 from a single sediment core from Standley Lake
Dow, 1974	Summary of selected radionuclide concentrations measured in 1973 by EPA and CDH in Standley Lake sediments
EPA, 1975	Plutonium concentrations measured in 1973 in Standley Lake sediments--also includes plutonium concentrations measured in 1974 in sediments of several Front Range reservoirs believed to be unaffected by releases from the RFP
EPA, 1973	Plutonium and uranium concentrations measured in 1970 in Standley Lake sediments and water (uranium data for water only)
Rockwell, 1988b	Summary of plutonium concentrations in Standley Lake sediments

TABLE 2.1
DATA SOURCES, SITES 200 - 202, ROCKY FLATS PLANT
(continued)

STANDLEY LAKE	
Data Source	Nature of Data
Rockwell, 1986a	Summary of selected radionuclide concentrations in Standley Lake water and in municipal water supplies around the RFP, and summary of plutonium concentrations in Standley Lake sediments.
Rockwell, 1984	Plutonium concentrations measured in 1984 in Standley Lake sediments
Thompson, 1973	Summary of selected radionuclide concentrations measured in 1973 by various agencies in Standley Lake sediments

MOWER RESERVOIR	
Data Source	Nature of Data
Rockwell, 1987	Plutonium concentrations measured in 1977, 1985 and 1986 in surface soils on lands adjoining Mower Reservoir
Rockwell, 1979b	Plutonium concentrations measured in 1976 and 1977 in surface soils on lands adjoining Mower Reservoir
Dow, 1972	Plutonium concentrations measured in 1972 in surface soils on lands adjoining Mower Reservoir

GENERAL DATA SOURCES	
Data Source	Nature of Data
CSM, 1990	Plutonium and cesium-137 concentrations in two Front Range reservoirs believed to be unaffected by releases from the RFP--also includes estimates of sedimentation rates for these reservoirs
EG&G, 1990	Aerial radiological survey of the RFP environs, including Great Western Reservior, Standley Lake and Mower Reservoir

TABLE 2.1
DATA SOURCES, SITES 200 - 202, ROCKY FLATS PLANT
(continued)

GENERAL DATA SOURCES	
Data Source	Nature of Data
"Environmental Surveillance Report on the U.S. Department of Energy's Rocky Flats Plant" (published monthly by the Colorado Department of Health and presented at monthly information exchange meetings)	Summaries of reservoir and drainage water quality monitoring data and air quality monitoring data collected in the environs of the RFP during the current month
"Rocky Flats Plant Monthly Environmental Monitoring Report" (published monthly by EG&G Rocky Flats, Inc.)	Summaries of reservoir and drainage water quality monitoring data and air quality monitoring data collected in the environs of the RFP during the current month
"Rocky Flats Plant Site Environmental Report" (published annually since 1971 by EG&G Rocky Flats, Inc. and their predecessors; known prior to 1988 as "Annual Environmental Monitoring Report")	Summaries of all environmental investigations and monitoring conducted on and around the RFP during the current year
"Annual RCRA Ground-Water Monitoring Report for Regulated Units at Rocky Flats Plant" (published annually by EG&G Rocky Flats, Inc.)	Summaries of ground water monitoring data from RCRA regulated units at the RFP

TABLE 4.1
PROBABILITY OF OCCURRENCE AND QUALITATIVE RISK
SITES 200-202, ROCKY FLATS PLANT

Primary Release Mechanism	Probability of Occurrence of Contaminant in Media	Secondary Source	Secondary Release Mechanism	Probability of Occurrence of Contaminant in Media	Importance to Risk Assessment	Magnitude of Qualitative Risk
Fugitive dust from exposed sediments	low-negligible	Air	Airborne settled dust-plant settled dust-soil settled dust-water	low-negligible negligible low-negligible negligible	critical marginal marginal marginal	low-negligible negligible negligible negligible
Wind stripping of water	negligible	Air	airborne	negligible	marginal	negligible
Reservoir discharge	low-negligible	Surface Water	Biotic Uptake Deposition Irrigation Infiltration Fugitive dust erosion	negligible negligible negligible negligible negligible	marginal marginal marginal marginal marginal	negligible negligible negligible negligible
Drinking water withdrawal	negligible	Treatment Plant	tap water	negligible	marginal	negligible
Ground water infiltration	negligible	Ground Water	seepage pumpage transfer to surface water	negligible negligible negligible	marginal marginal marginal	negligible negligible negligible negligible
Biotic uptake	negligible	Biota	biodegradation	negligible	marginal	negligible

TABLE 4.2
ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION
SITES 200-202, ROCKY FLATS PLANT

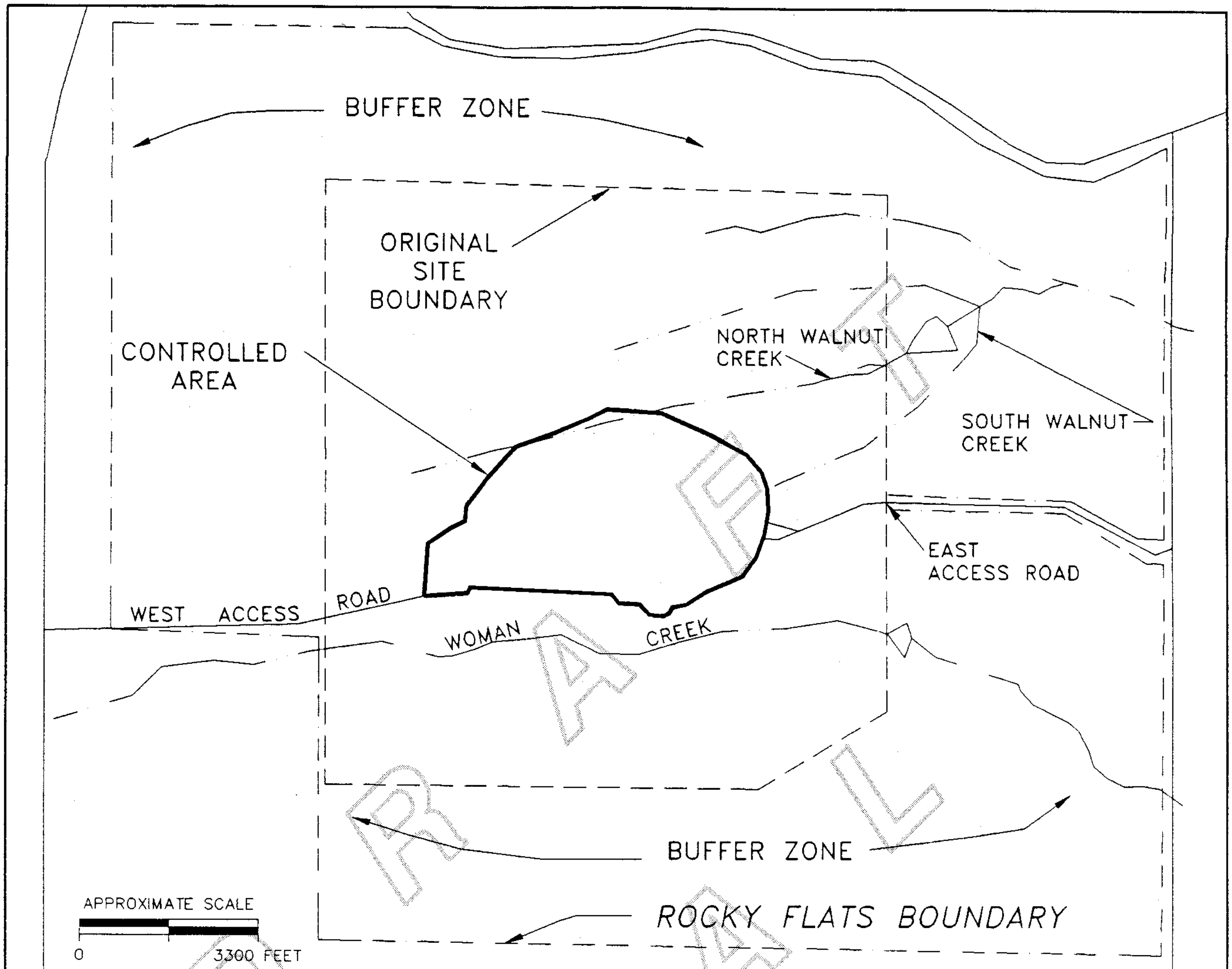
Assumption	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Environmental Sampling and Analysis			
Sufficient samples may not have been taken to characterize the matrices being evaluated.			Moderate
Systematic or random errors in the radiochemical analyses may yield erroneous data.			Low
Plutonium concentrations reported as "below method detection limit" are considered to be a non-detect data point.		Low	
The qualitative public health evaluation is based on the chemical of concern (Pu) only. This may represent a subset of the radionuclides possible at the site.		Moderate	
Exposure Parameter Estimation			
The standard assumptions regarding body weight, period exposed, life expectancy, population characteristics, and lifestyle may not be representative for any actual exposure situation.			Moderate
The amount of media intake is assumed to be constant and representative of the exposed population.	Moderate		
Exposure to contaminants remains constant over exposure period.	Moderate		

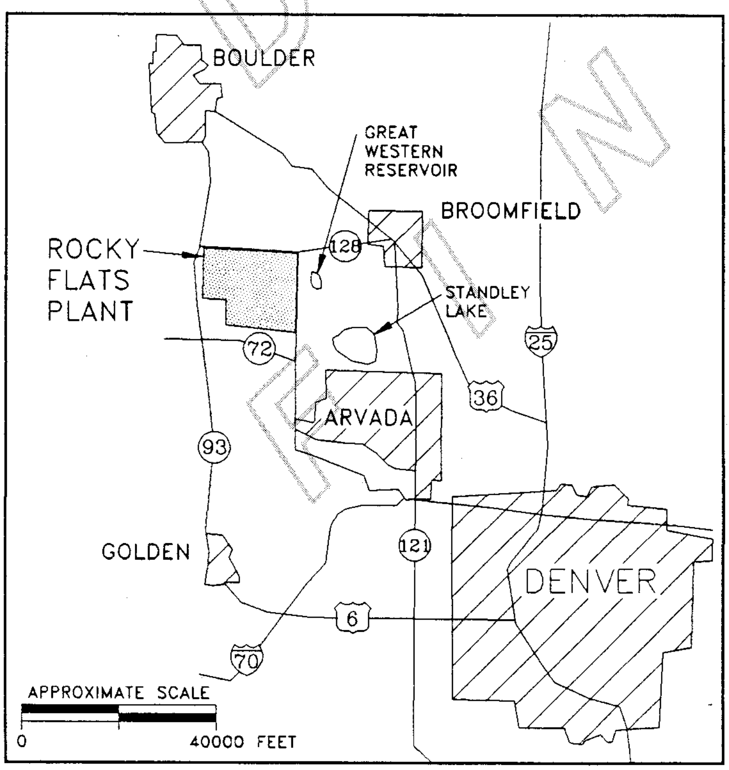
TABLE 4.2
ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION
SITES 200-202, ROCKY FLATS PLANT
(continued)

Assumption	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Concentration of contaminants remains constant over exposure period.	High		
All plutonium is available for inhalation in respirable-size particles.	High		
For most contaminants all intake is assumed to come from the medium being evaluated. This does not take into account other contaminant sources such as diet, exposures occurring at locations other than the exposure point being evaluated, or other environmental media which may contribute to the intake of the chemical (i.e., relative source contribution is not accounted for).		Moderate	
Environmental Parameter Measurement			
Food does not contribute to plutonium uptake.		Moderate	
Dermal absorption of pluronium from soil is negligible.		Low	
Toxicological Data			
Risks are assumed to be additive. Risks may not be additive because of synergistic or antagonistic actions or other chemicals.			Moderate

TABLE 4.2
ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION
SITES 200-202, ROCKY FLATS PLANT
(continued)

	Effect on Risk		
Assumption	May Over-Estimate Risk	May Under-Estimate Risk	May Over/Under-Estimate Risk
Assumes absorption is equivalent across species. This is implicit in the derivation of the acceptable intakes or cancer slope factors in this assessment.			Low
Extrapolation of toxicity data from species to species, and from laboratory animals to animals in the field.			Moderate





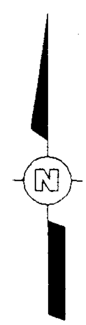


FIGURE 1-1

ROCKY FLATS LOCATION MAP

ADAPTED FROM: FIG. 1-1, E.G. & G. DRAFT GEOLOGIC CHARACTERIZATION REPORT, JAN. 3, 1990.

DRAWN BY	KRONER	10/4/90
CHECKED BY	CJR	10-18-90
APPROVED BY	TDK	10-18-90
DRAWING NUMBER	304923-A6	

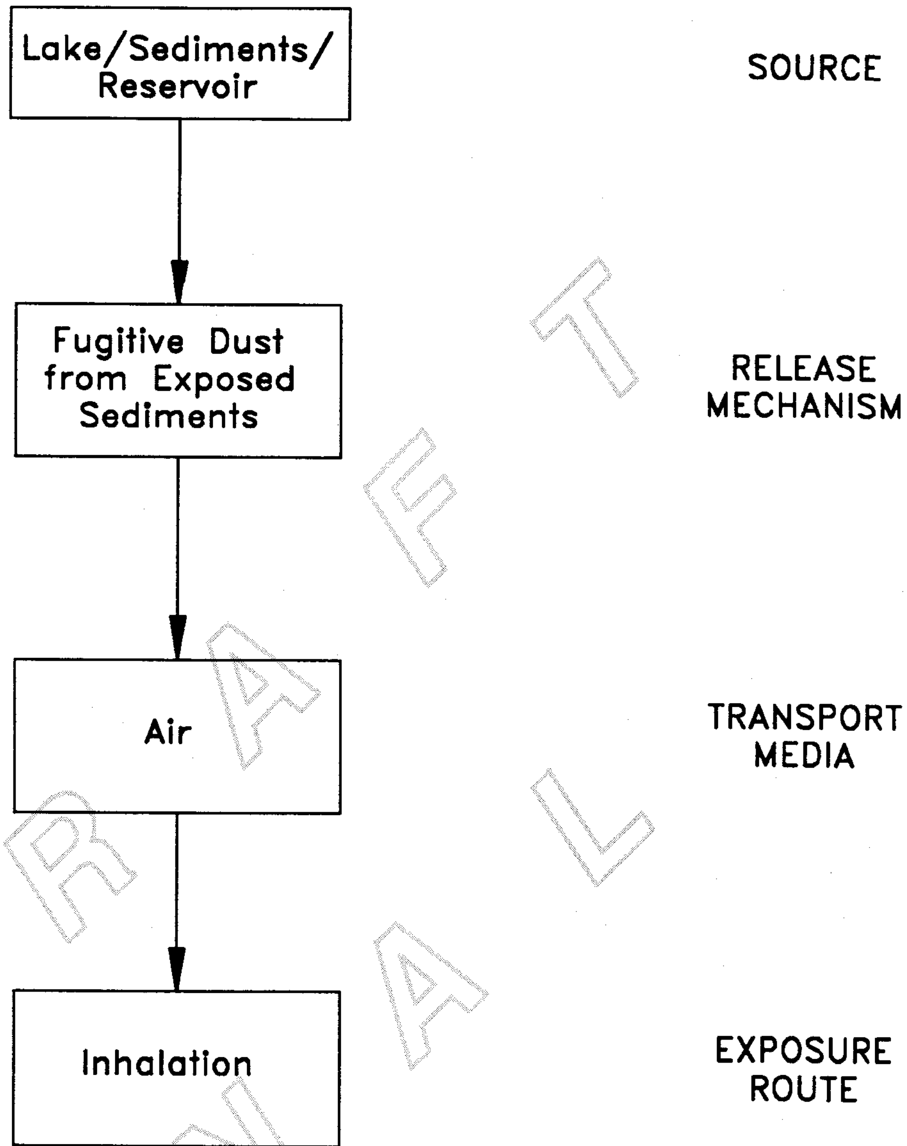
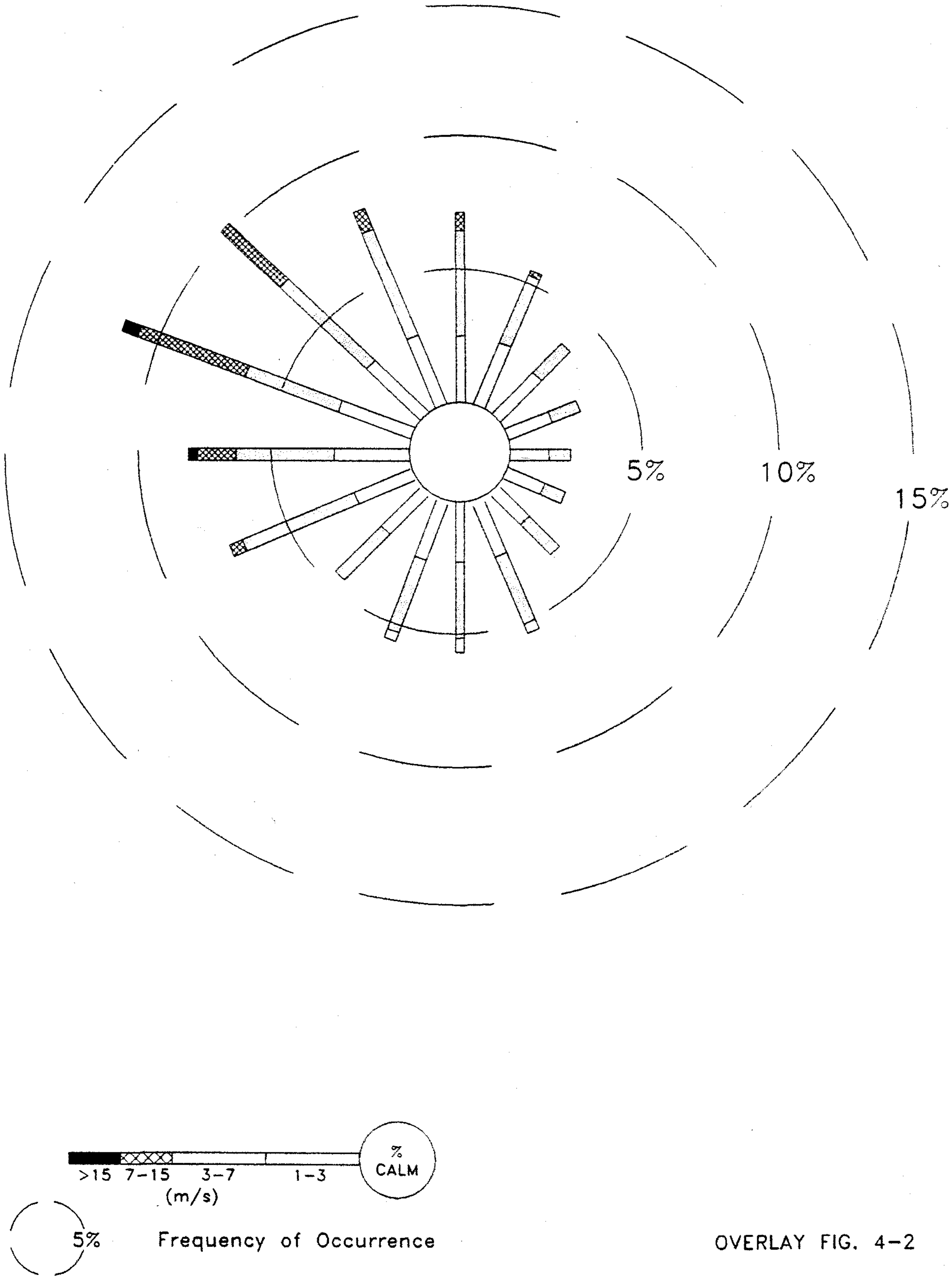


FIGURE 4-1

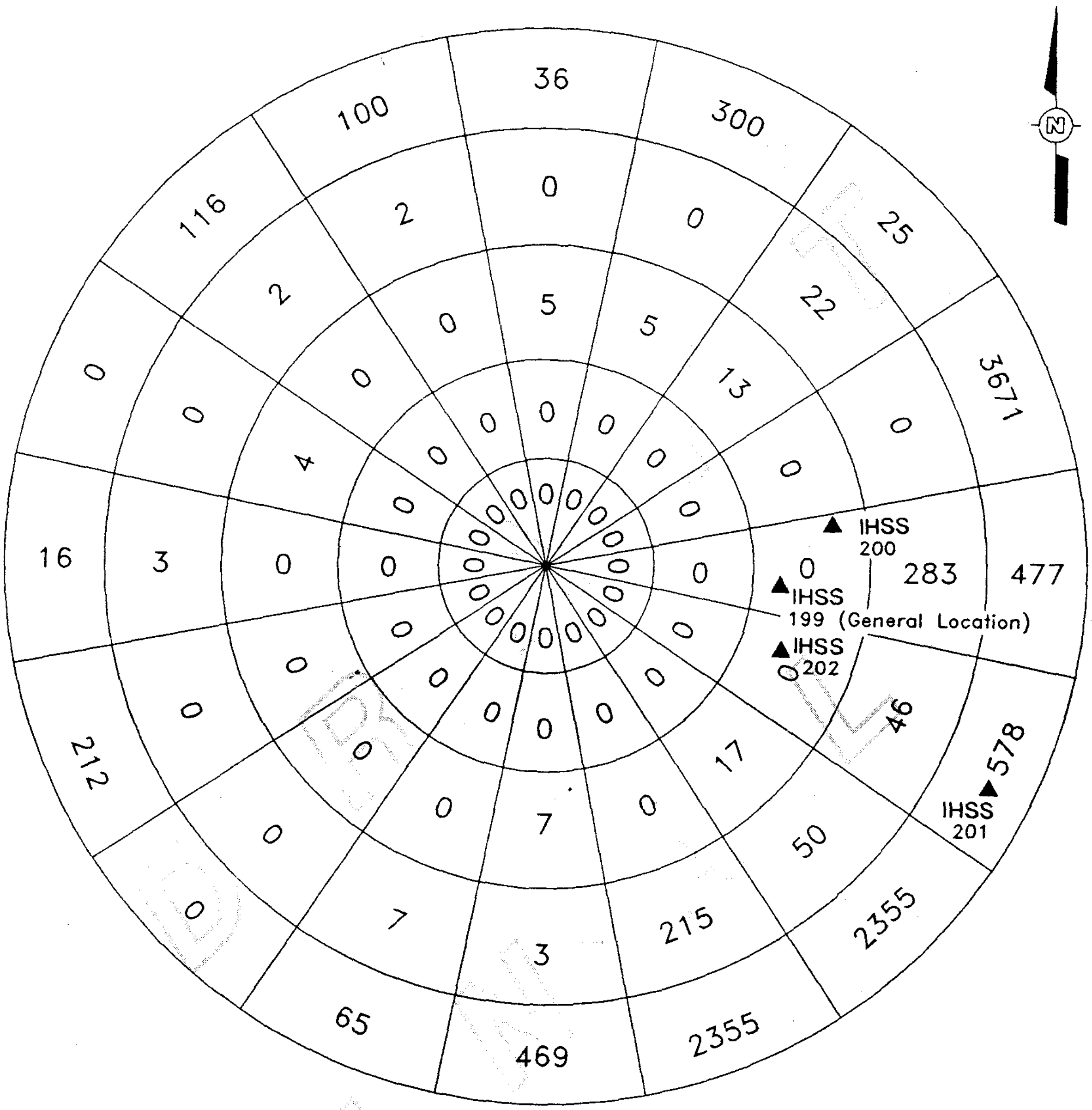
COMPLETED EXPOSURE PATHWAYS,
SITES 200-202
QUALITATIVE RISK
ASSESSMENT

DRAWN BY	KRONER 10/4/90	CHECKED BY	CJR	11-2-90	DRAWING NUMBER	304923-A1
		APPROVED BY	CJR	11-2-90		



OVERLAY FIG. 4-2

DRAWN BY KRONER 8/24/90 | CHECKED BY CJR 10-16-90 | APPROVED BY TDK 10-16-90 | DRAWING NUMBER 304923-A4



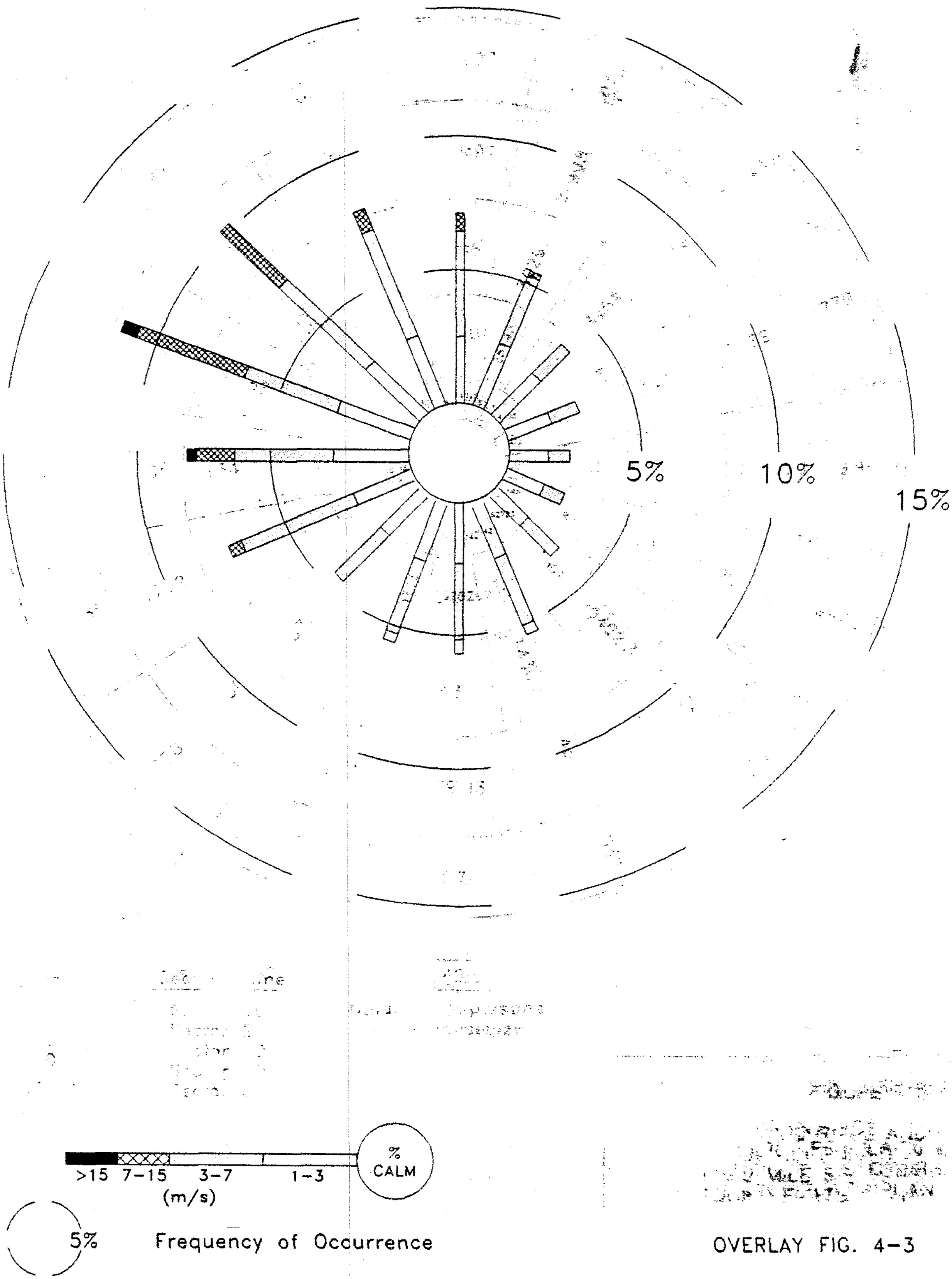
Miles	Sector Name
0–1	Sector 1
1–2	Sector 2
2–3	Sector 3
3–4	Sector 4
4–5	Sector 5

65 — Number of persons living in sector

FIGURE 4-2

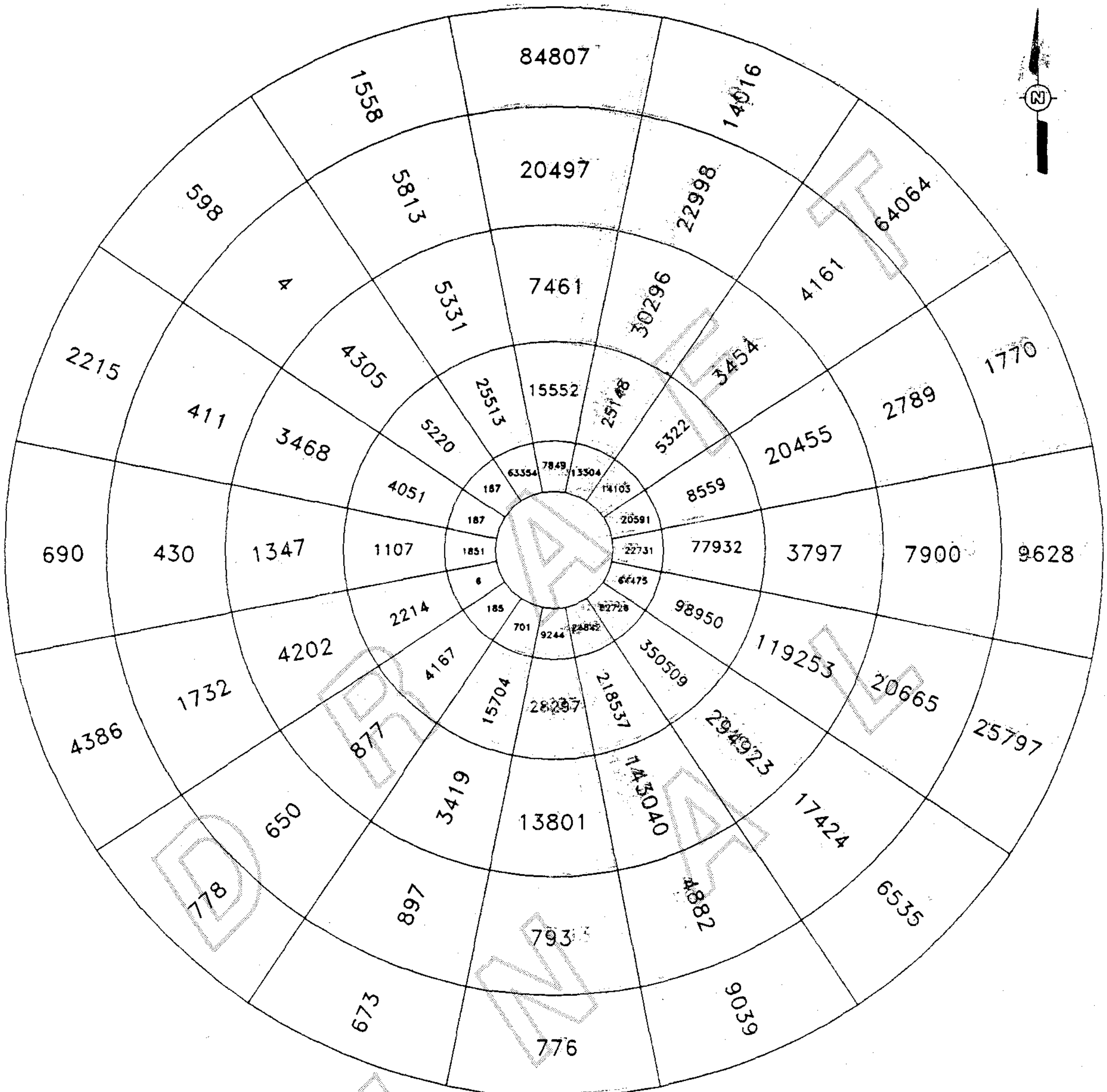
WIND ROSE AND 1989 POPULATION, 0-5 MILE SECTORS, ROCKY FLATS PLANT

REFERENCE: FIGURE 2–1, DOE, 1989 POPULATION, ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT.



OVERLAY FIG. 4-3

DRAWN BY KRONER 8/24/90 | CHECKED BY CJR 10-16-90 | APPROVED BY TDK 10-16-90 | DRAWING NUMBER 304923-A3



Miles	Sector Name
5–10	Sector 10
10–20	Sector 20
20–30	Sector 30
30–40	Sector 40
40–50	Sector 50

65 Number of persons living in sector

FIGURE 4-3

WIND ROSE AND 1989 POPULATION, 10-50 MILE SECTORS, ROCKY FLATS PLANT

REFERENCE: FIGURE 2-4, DOE, 1989 POPULATION, ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT.

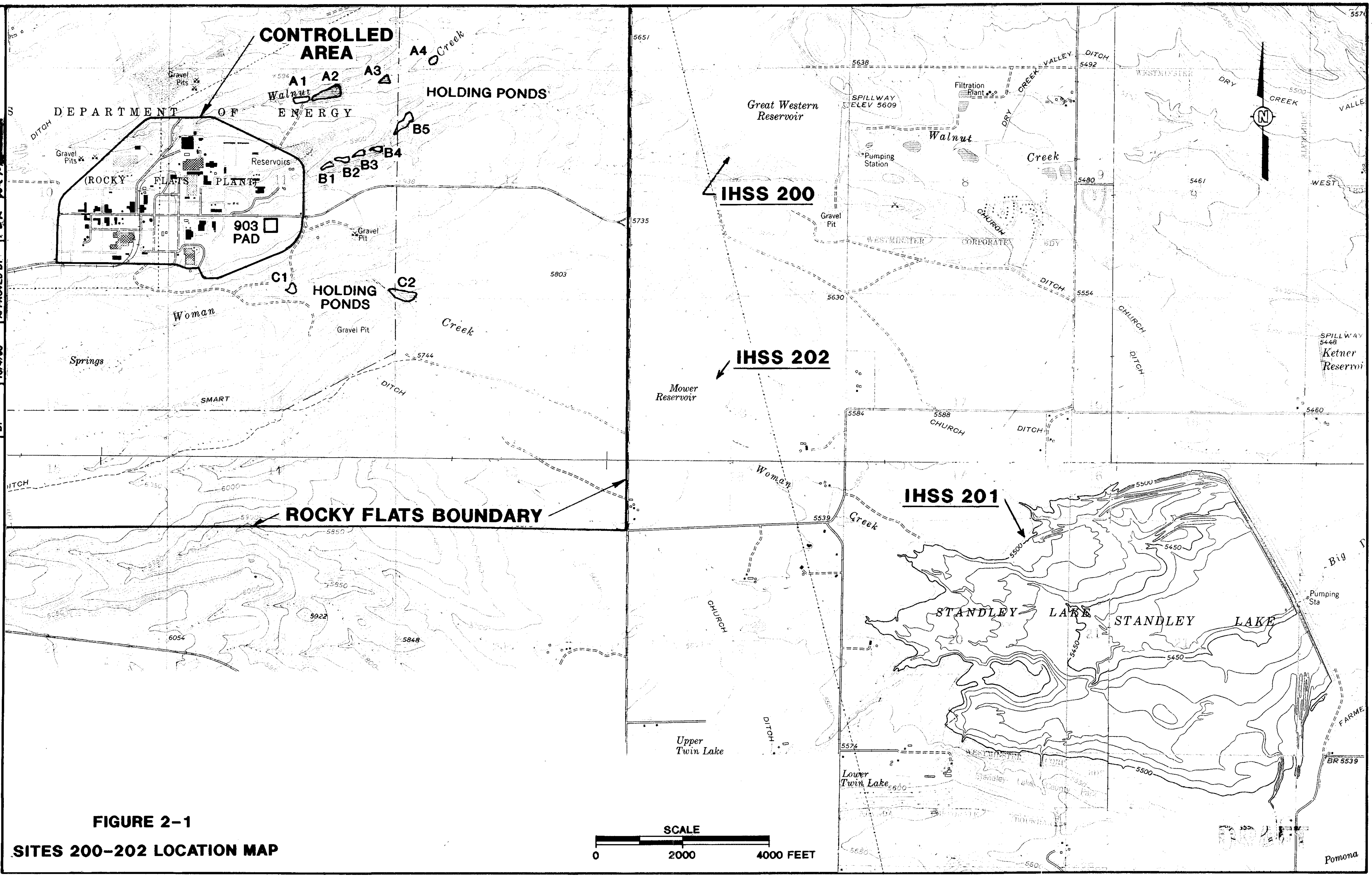


FIGURE 2-1

SITES 200-202 LOCATION MAP

DRAWN BY	KRONER 10/4/90	CHECKED BY APPROVED BY			304923-B4

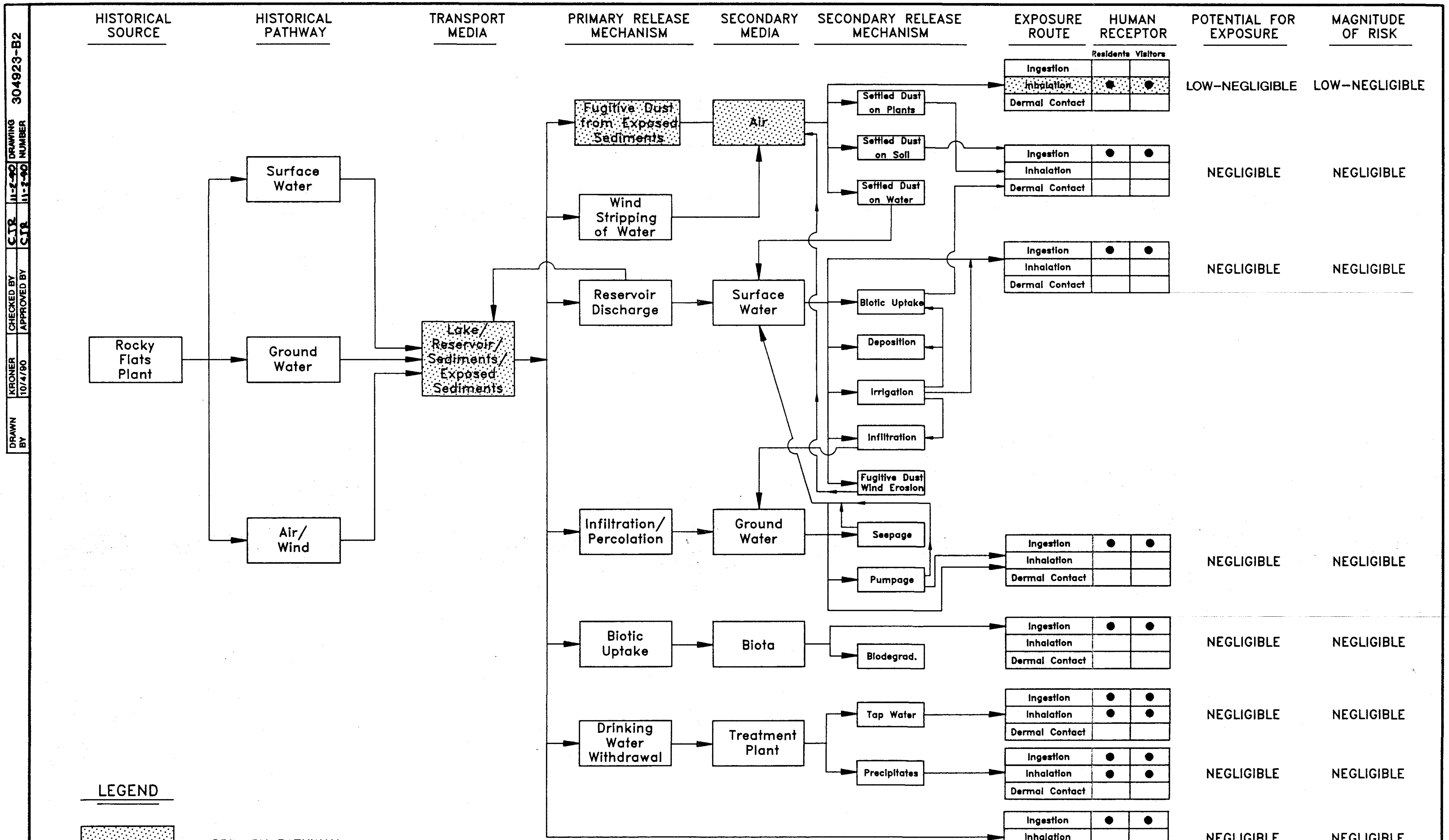


FIGURE 3–1
CONCEPTUAL MODEL,
SITES 200–202,
OFF-SITE RESERVOIRS

492382